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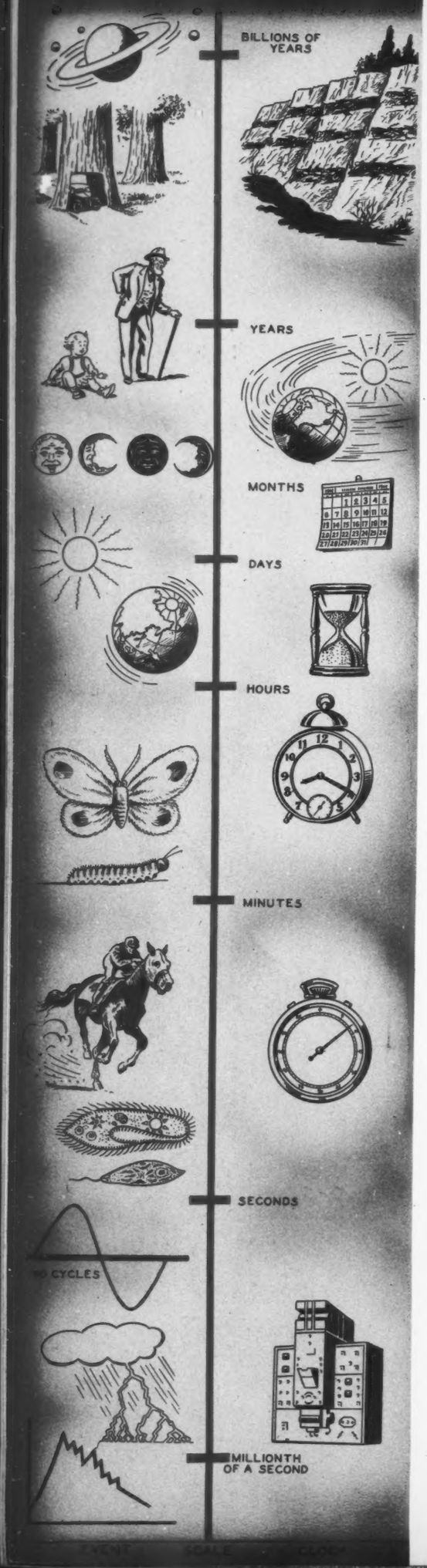

The Time Microscope

The time spectrum is in many ways similar to the electromagnetic frequency spectrum. Both have an incomprehensible range in scale. The electromagnetic scale extends up from the low frequencies used in electric power transmission to billions of cycles per second in the little-known cosmic-ray region. At the upper end of the time spectrum lie events in the cosmos in which the time units could be many billions of years. The life span of recorded human history, measured in a few millenniums, occupies but a narrow band somewhere in the middle of the time scale, much as does the band of visible radiation in the frequency spectrum. The life span of an individual is as but one spectral line. An insect lives but a few hours, a simple cell completes its life cycle in a few minutes, a lightning flash exists but a few millionths of a second. At or near the bottom of our time scale lie certain electrical phenomena that come and are gone in a fraction of a millionth of a second. Electrical engineers call them transients.

To measure the span of events of such wide difference in duration, we have the life of a star, radioactive transformations, rocks themselves, the saltiness of the ocean, the calendar, the rotation of the earth, the clock, the stop watch. To these must be added the cathode-ray oscillograph, which is readily able to record the life history of a transient as brief as one tenth of a millionth of a second. If this time were expanded to a full second, a full day on the same basis would be 28 000 years.

Before the electronic oscillogragh was developed, progress in many branches of electrical engineering was hampered by the lack of an ultra-high-speed writing device, because the effect and characteristics of very fast transients could not be determined. In those days peculiar, unexplainable accidents were blandly laid to little-known transients, whose mystery has been bared by the cathode-ray oscillograph.

The pencil with which the cathode-ray oscillograph writes is a stream of electrons; the hands that move the pencil are electrostatic fields. Clear traces, scribed at the rate of two inches in one twentieth of a microsecond, are not uncommon, which means the electron finger can move with a speed of more than 36 000 miles per minute. If the oscillograph were allowed to write in a straight line at full speed for a second, it would require a film over 600 miles long.

The electrons are hurled at their "manuscript," which is ordinary photographic film, at speeds of 75 000 miles per second, four tenths of the speed of light. Although the current striking the film is only one one-hundredth of a milliampere, to write a 0.1 microsecond record, a total of about six million electrons will strike the film. A lot of electrons? Indeed no, almost none at all. The current of a 15-watt lamp represents the movement of over 136 000 times that many electrons.

The electron beam does its writing in a vacuum. It is not a "hard" vacuum as vacuums go, about two microns in the recording part of the instrument where the beam does the writing. (A micron is one thousandth of a millimeter of mercury or about 1/25 000 of sea-level atmosphere.) However, it is extremely sensitive to changes in pressure, as was shown in an odd way one day. It is common practice to keep pumping out the oscillograph to a pressure considerably below what is desired, and to allow the pressure to build up to the exact amount by a controlled leak from the atmosphere. An experimenter was having difficulty maintaining a steady cathode beam. It was then observed that an air hammer was working near by. The pressure waves from the air hammer were sufficient, through the needle valve, to affect the beam. This led to the present system of using a bellows-type air reservoir from which the trickle of air is allowed into the evacuated chamber to maintain the correct degree of vacuum. In this way instability of beam action occasioned by variations in atmospheric pressure are avoided.

WESTINGHOUSE

Engineer

VOLUME FOUR NOVEMBER, 1944 NUMBER SIX

On the Side

The Cover—The indoor substation with air-insulated equipment, pictured by artist F. G. Ackerson, was described briefly in our last issue by A. C. Monteith, and in greater detail in this issue.

• • •

We have seen pictures of G. I.'s in transparent bags to protect them from poison gases, pictures of guns, ordnance, and food sealed in synthetic covers for shipment to tropical and polar battle areas. But these exploits of packaging experts pale beside the sealing of eight-car power trains. Shipping these trains (described on p. 176) to Europe, required that each car be completely sealed against moisture to withstand the open-deck sea voyage. How this was done will be described later.

• • •

One hundred and forty thousand barrels of oil, vital to fleet operations in the Pacific, were faced with more than a month's delay because of breakdowns aboard a tanker carrying it to the war area. Incapacitated off Panama, the tanker was over 2000 miles from replacement parts. An 8500-pound generator armature was expressed from East Pittsburgh to New York and flown by Naval Air Transport to Panama. Installation was started the fourth day after the call for help. A replacement turbine rotor started on its 2000-mile trip by air the next day. The 10 500-pound rotor and some 2000 pounds of trim ballast made the trip from factory to ship in less than four days. Two weeks for two 2000-mile trips and two major installations meant a saving of at least two weeks over normal transportation means. In the critical Enewitok—Saipan—Guam period, who can evaluate the worth of those two weeks?

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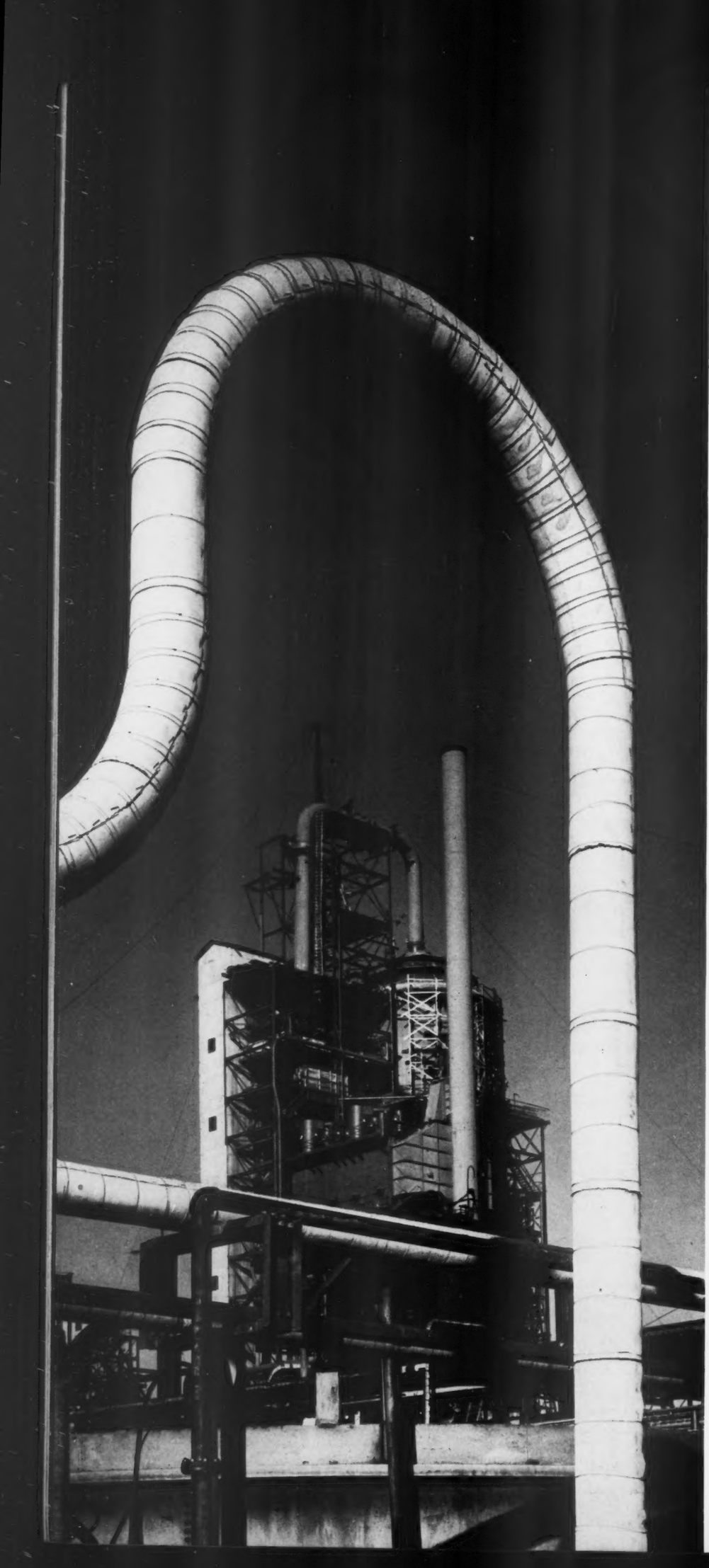


High-Octane Fuel

Automobiles, noisily protesting the absence of several octane numbers from wartime gasoline, make us octane-rating conscious. Fabulous stories of airplane performance with 100-octane super-fuel bring visions of future cars, smaller, lighter, and doubled mileage—visions likely to materialize, but not quickly.

HISTORY may record that victory for the Allies in World War II hinged on the number 13. In the battle of Britain the RAF pilots fought with 100-octane fuel; the Nazis had 87. The British won. In spite of the unconquerable spirit of the English fliers, it is extremely doubtful if they could have turned back the determined invaders without the extra rate of climb, higher speed, greater maneuverability possible with the higher octane fuel.

An airplane can be built to fly one fourth farther on a given amount of 100-octane gasoline than on 87. Or, of two big bombers flying to a target 1000 miles distant, the one using 100-octane fuel can carry 5000 pounds more bombs than the one burning 87 octane. The extra power available from higher octane fuel can similarly be spent on some combination of air-fighting advantages, such as additional armor, higher ceiling, greater agility in "dog fighting," and shorter take-off.

The Liberty engine developed about 400 hp on fuel of about 55-octane number. Today's Allison engine with the same number of cylinders and almost the same piston displacement, but burning 100-octane gasoline, develops almost four times as much power. Gasoline of 100-octane rating enables designers to increase supercharging and raise the compression ratios to a point that packs several times more power into the engine. The higher power results from the difference in octane number of the gasoline and by the boosted inlet pressure, which the better fuel makes possible, and by higher engine speeds resulting from mechanical improvements in the engine itself.

The average citizen who possibly may never fly a plane is anxious to translate the significance of this marvelous fuel into terms of his postwar automobile. Like most questions,

Invaluable assistance in the preparation of this article was provided by numerous individuals of several companies. Among these organizations are: the Lummus Company, Standard Oil Company of New Jersey, Gulf Research and Development Company, Gulf Oil Company, Ethyl Corporation, Research Laboratories Division of General Motors Corporation, Chrysler Corporation, Thompson Products Inc., Petroleum Industry Council for War, and Petroleum Administrator for War.

ts Production and Significance

the answers to what kind of fuel will be available for automobiles when the war is won, and how it will affect the design of the postwar car and its performance cannot be given simple, categorical terms. First we must learn about knock.

Stop That Knock

An aircraft engine allowed to knock may destroy itself in two minutes. On one occasion a plane was fueled with 80 octane instead of 87. Five cylinder heads failed during take-off. Knock cannot be tolerated in aviation engines. Knock in automobile engines is not as serious. However, it means loss of power and rapid rise in motor temperature, which, if prolonged, would be injurious.

When a fuel begins to burn in a cylinder, the rapidly expanding combustion gases compress the remaining unburned fuel and raise its temperature. If the temperature and pressure reach a certain critical figure depending on that particular fuel, the remainder of the fuel burns explosively instead of progressively. It detonates. When this occurs, the molecules strike the cylinder and piston surfaces with utterly fantastic velocities, as yet unmeasured. Even with slow-motion pictures, taken at 200 000 frames per second, the action appears instantaneous. This causes rapid vibration of the cylinder structure, heard as knock. Also, it causes rapid heating of combustion-chamber parts. Some of the energy normally converted into power at the crankshaft is dissipated as heat through the engine structure. Also, serious damage or destruction of the engine parts such as pistons and piston rings may result from overheating. Detonation, then, is a bottleneck to useful power production from a given fuel. It sets the limit on compression ratio, air-injection pressures, permissible spark advance, and other expedients to more powerful or more efficient burning of the fuel. Or, to put it differently, elimination of detonation by the use of higher octane fuels permits raising the compression ratio or increasing the amounts of air and fuel charged to the engine. The increased compression ratio results in more efficient conversion of the heat energy of the fuel to useful work, while supercharging increases the amount of fuel packed into the cylinder, thereby increasing the power output without materially affecting the efficiency. An engine is working most efficiently when it is just on the verge of knocking.

The Meaning of Octane Number

Octane number relates solely to the tendency of gasoline to knock in internal-combustion engines. Antiknock rating does not control the efficiency, miles per gallon, or horsepower available from the fuel. Raising the octane number of a fuel does not necessarily increase its energy content by even one Btu per pound. The total heat content may, in fact, be less. The octane rating is a measure of whether a fuel will or will not detonate, which is ordinarily the factor limiting the horsepower an engine can deliver. Raise the octane number, and you make it possible to build an engine to use the fuel to give either greater horsepower per pound of engine or more work per pound of fuel, and sometimes both.

The octane scale was proposed in 1926 by Dr. Graham Edgar, now vice president of the Ethyl Corporation, to re-

Alkylates, made in plants like this one of the Standard Oil Company of New Jersey at Baton Rouge, Louisiana, have provided most of the blending agents for aviation gasoline. Alkylate is a mixture of iso-octanes, which in performance is the "gold standard" of the octane scale.

duce the chaotic condition of fuel ratings resulting from the steady improvement in refinery products and the growing use of Ethyl fluid (lead tetraethyl) to reduce the knock tendency of gasoline. Like the Centigrade and Fahrenheit temperature scales, it was based on arbitrarily chosen limits. Normal heptane, a petroleum product notorious for its knocking properties, was chosen for the zero or base line of the octane scale. Iso-octane, one of the hydrocarbons that had just previously been isolated in small quantity at high cost, had such superior antiknock tendencies as compared to commercial fuels that it was considered suitable for the upper standard or 100 on the octane scale.

The octane number of a motor fuel is determined by matching it against mixtures of normal heptane and iso-octane in a test engine under specified test conditions until a mixture of the pure hydrocarbons is found that gives the same degree of knocking in the engine as the gasoline being tested. The octane number of the gasoline is, then, the percent of iso-octane in the matching iso-octane-heptane mixture. For example, a gasoline equivalent in its knocking characteristics to a mixture of 60-percent iso-octane and 40-percent normal heptane is given a rating of 60 octane.

This manner of knock-rating gasolines served well—until the petroleum industry overran its own standard of perfection. Several years ago, refiners learned how to blend engine fuel that was superior even to pure iso-octane in knock value. Clearly, numbers above 100 on the present octane scale are meaningless. Several new methods of rating fuel have been proposed, but none has yet been adopted as standard.

A fuel that has a given octane number under one engine condition may have a quite different rating at some other condition. This is why we hear of different test methods. The one best known to the public and generally meant unless otherwise specified is the ASTM or Motor Method, but there are others used within the industry.

A Lift from Ethyl

Pilots in World War I were aware of a great difference in the tendency of various gasolines to knock. In general, gasoline made from California stocks had somewhat less propensity to knock than those from Texas, which in turn were better than the Pennsylvania gasolines. Why, no one knew, and as to the fundamental mechanism, still no one knows.

Without understanding this mystery of hydrocarbons, engineers and chemists set out to develop fuels that are less prone to detonate. Small amounts of various substances added to a fuel were known to improve its knock value. Iodine was one of the first ones discovered, but it was corrosive. Thomas Midgley, Jr. and his associates at General Motors discovered that tetraethyl lead (usually just called lead or Ethyl) in minute quantities works wonders with almost all gasolines. How it is that one molecule of lead among 200 000 molecules of fuel decreases detonation is a miracle of chemistry that still remains a mystery.

Whatever its secret, one or two spoonfuls of lead added to a gallon of gasoline raises the knock rating several octane numbers. Adding more lead continues to improve the antiknock qualities of the fuel but at a declining rate.

Tetraethyl lead, valuable though it is, does nothing more than improve the antiknock qualities of a gasoline. It is an octane-number booster. It does not increase the energy (Btu) of a fuel but increases the power that can be obtained from a suitable engine, because it permits a design in which the compression ratio is increased.

Many Routes to High-Octane Fuel

Gasoline is not just a single hydrocarbon compound. Any particular gasoline may consist of hundreds, perhaps thousands of different compounds in a wide variety of proportions. Of the enormous family of hydrocarbons that constitute crude oil as it comes from the ground, the gasoline hydrocarbons are relatively a small band of the middleweights, with boiling points over the temperature range from below 100 to about 400 degrees F. The gamut of octane ratings covered by different hydrocarbons in the gasoline range extends from below zero to well above 100.

To manufacture gasoline from the black, smelly crude oil as nature made it, the first and logical thing to do is to separate the gasoline-range hydrocarbons that are already in it. This is accomplished by the relatively simple process of heating the crude oil in a still. At the correct temperature and pressure the gasoline comes off as a condensible vapor, leaving behind the heavier molecules that are the kerosenes, fuel oil, lubricating oil, and the many, many others. This gasoline is called straight-run. Twenty-five years ago, simple distillation was the only method, but now it is only one of several.

The octane rating of straight-run gasoline is quite low, averaging from 40 to 60. By careful selection of the crude-oil base stocks, straight-run gasolines of higher octane values —of the order of 74—are produced. Adding lead to the better grades of straight-run gasolines produced much of the prewar aviation fuels of 87 to 91 octane.

Considerable "natural" gasoline is obtained

These Westinghouse motors in an oil refinery are indicative of the great amount of electrical equipment required by the petroleum industry. Of $540 000 000 spent to increase our production of aviation gasoline, 54 millions were for boilers, turbines, pumps, blowers, and compressors. Motors, control, switchgear and other apparatus account for $13 000 000 more.

by catching the gasoline vapors carried over with natural gas.

The popularity of the automobile during the 20's rose swiftly. Groves of gasoline pumps sprung up, sometimes on all four corners of an intersection. The demand for gasoline could not be met economically by straight-run methods alone, which yield only about 20 barrels of gasoline from each 100 barrels of crude. A higher yield of gasoline from the crude was needed to be converted to gasoline to prevent waste of petroleum reserves.

Refineries met this call by thermal cracking, by which gas oil (the petroleum fraction next heavier than kerosene) is subjected to high temperatures (850 to 1200 degrees F) and high pressures (up to 1000 pounds). Some of the heavier hydrocarbon molecules are broken up or "cracked" into lighter ones, in the gasoline range. By this procedure the average amount of gasoline from a given crude is more than doubled—to about 45 barrels of gasoline from 100 of crude stock. This increase, of course, comes at a sacrifice of other petroleum products, but this is acceptable as the great demand has been for gasoline.

Fortunately, cracked gasoline has a higher antiknock value than straight-run gasoline. Octane numbers of 70 to 75 are not uncommon for thermally cracked gasolines made from selected crudes. These can be boosted by the addition of lead, although not to the same extent as with straight-run gasolines. Because of poor oxygen stability (gum formation), however, thermally cracked gasolines are not used for high-rating aviation fuels. Gases required in making high-octane blending agents and in synthetic-rubber manufacture are important by-products of thermal cracking.

Until shortly before this war, gasolines from the pumps at the neighborhood filling station were made of blends of straight-run and thermally cracked gasoline and Ethyl fluid. Approximately, 90 percent of all gasoline manufactured contained tetraethyl lead in various amounts. Premium gasoline had an octane rating of about 80, regular was about 74-octane number, and third-grade gasoline, about 64 octane.

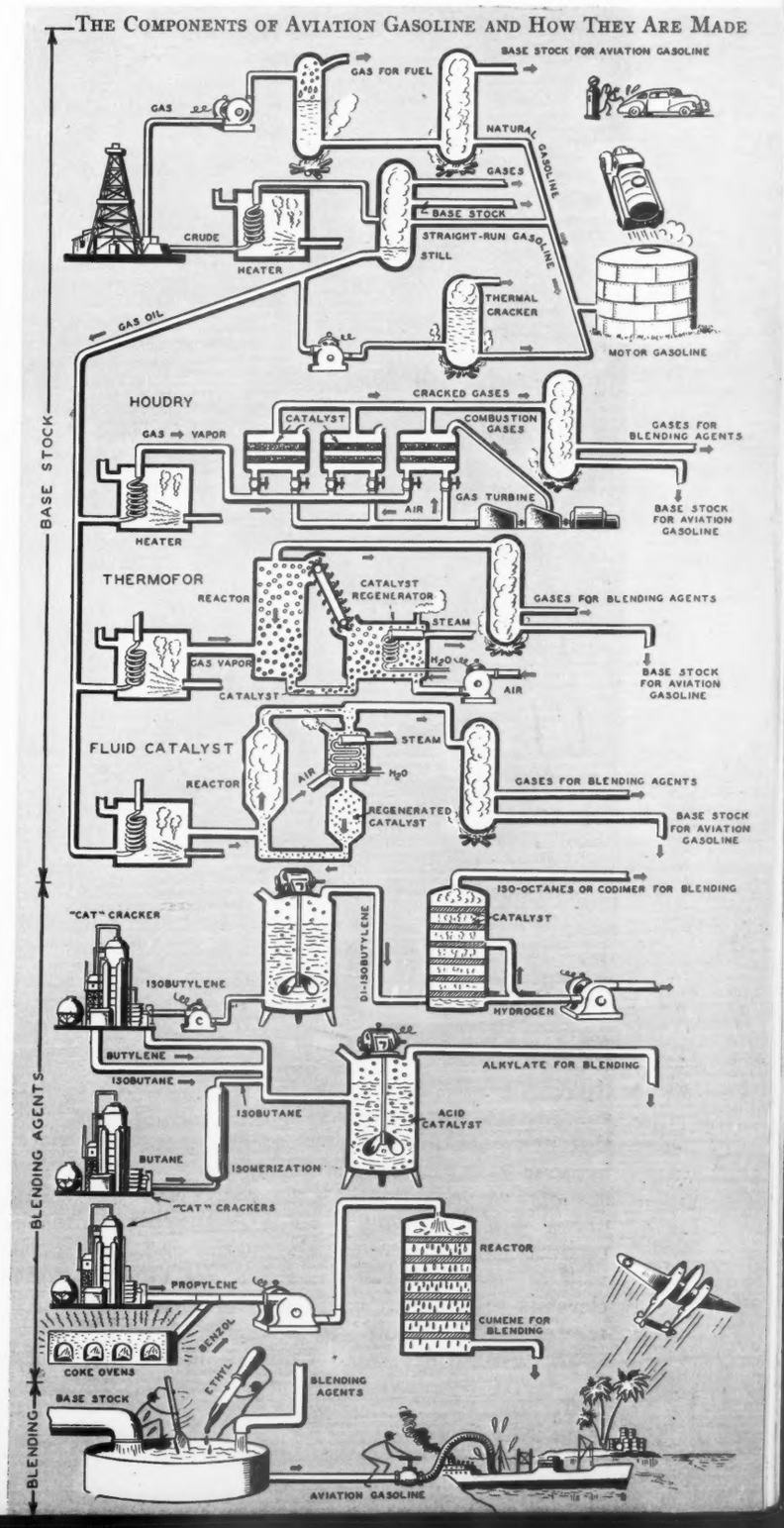
"Cat" Cracking

In thermal cracking, gasoline is produced by the application of heat and pressure alone. The introduction of catalytic cracking in 1938 gave the refiner a better means of controlling the cracking reaction. The use of a catalyst in the cracking process produces a greater yield of higher octane gasoline from the charging stock because reactions that occur at lower temperatures and pressures can be better controlled. During the cracking reaction, gases and coke are also formed, but many of the gases are valuable for the production of blending agents for 100-octane fuel (discussed later) and for the manufacture of synthetic rubber.

Catalytically cracked gasolines have higher antiknock ratings than either the thermally cracked or straight-run fuels. Unlike thermally cracked fuel, catalytically cracked gasolines are suitable for the production of 100-octane gasoline. Furthermore, catalytic-cracking units are more flexible than thermal units. They can be operated to produce large quantities of isobutane and butylene gases as by-products, which can in turn be used in the production of alkylate, an aviation-fuel blending agent, and as raw materials for synthetic rubber. "Cat" cracking has been of incalculable value to the war aviation fuel program.

Catalytic-cracking plants are of three types. One, the Houdry, utilizes a fixed or stationary catalyst bed. In the other two, the Thermofor and the Fluid catalyst systems, the catalysts are continuously circulated with the petroleum vapors to be cracked. Various kinds of catalysts are used. Certain finely divided natural clays were used first. More recently, synthetic catalysts have been developed, which improve both yield and antiknock value of the fuel. All of them use as charge the hydrocarbon fraction known as gas oil, which is similar to kerosene.

The Houdry process is the oldest, the first commercial production beginning in 1936, and for this reason has been the one producing most of the catalytically cracked base stock for aviation gasoline. In it the catalyst beds are in fixed cases. The gas oil is vaporized by heat and is forced through the catalyst cases, the cracking reactions occurring en route.



As in all catalytic processes, carbon called coke accumulates on the catalyst, gradually "insulating" it or decreasing its activity. This coke must be burned off to revitalize the catalyst. In the Houdry scheme, the catalyst beds are fixed; hence, three cracking chambers are generally used to permit continuous operation by switching the flow of gas oil periodically to a freshly regenerated unit. The coke burning, incidentally, produces the hot combustion gases utilized in gas turbines for the production of mechanical or electrical power.

The catalytic-cracking processes in a single pass convert 40 to 50 percent of the gas oil charge into gasoline of 78- to 82-octane number. When making aviation fuel, the first-pass product is passed back through the unit once or twice under different operating conditions to alter its chemical composition. This special catalytic base is blended with alkylate, straight-run gasoline, and Ethyl fluid to make 100-octane aviation gasoline.

The Thermofor process, developed by Socony-Vacuum Oil Company and first used commercially about 1942, is a continuous catalytic-cracking process. Originally developed to use clay catalysts, Thermofor plants now use synthetic beads that, in size and appearance, resemble tapioca. In the cracking tower, the catalyst flows downward against the rising stream of vaporized gas oil. The products of the reaction are drawn off at the top of the tower and the spent beads move continuously out of the bottom to a kiln, where the accumulated coke is burned off, and thence back by bucket elevators to the cracking tower. The heat developed in regeneration of the catalysts is used to produce steam.

The so-called fluid-catalyst process, developed by Standard Oil Company of New Jersey and used commercially in 1942 is also continuous. The catalyst is really not a fluid but a chalklike dust of such fineness that when mixed with gases it behaves like a fluid. The fluid catalyst at 1000 to 1200 degrees F and the hot, vaporized charge are introduced at the bottom of the cracking tower. As they rise through the tower, the mass of powder and gases is thrown into violent agitation, which provides intimate contact between vapor and catalyst. Reaction products and catalyst are drawn off at the top of the reactor; the catalyst powder, now blackened with carbon, is separated in cyclone-type dust collectors. On its return for another trip through the reactor the catalyst is regenerated by burning off the coke. This type of plant has no mechanical handling of the catalyst. It depends for the continuous movement of enormous quantities of catalyst and vaporized charge on careful balances between vertical columns of downward moving fresh catalyst and upward moving stream of reacting gases and catalyst.

The amount of gasoline available from a given amount of crude oil has been tripled by various cracking processes, in which heavy hydrocarbon molecules are broken up and reformed into lighter ones within the gasoline range. Photograph by Standard Oil Company of New Jersey.

Blending Agents for Our High-Octane Cocktail

Enormous volumes of aviation fuel of 95 to 100 (and even higher) octane required by the Armed Forces have been made possible largely through the use of catalytically cracked base stocks. In addition, new blending agents to increase the quality and quantity of aviation fuel are required.

Use of iso-octane—the gold standard of the octane scale—suggests itself. Iso-octane alone is not usable as an aviation fuel, in spite of its superb antiknock quality, because it has too narrow a boiling range. Also, it costs too much. Furthermore, not enough pure iso-octane can be made.

Similar products such as alkylate and codimer can, however, be made in ample amounts at a low enough price for this purpose. These blending agents have high octane numbers and a wider boiling range, the latter quality making them more suitable as fuel for internal-combustion engines.

The earliest, and still one of the most important, method of making these members of the iso-octane family in large quantities is by polymerization, which is just the opposite of cracking. Instead of making lighter molecules out of heavy ones, the process builds bigger molecules from lighter ones. In the simplest case, two molecules of isobutylene, a gas evolved from refinery cracking coils and previously wasted, are induced by heat and pressure with a catalyst to form one molecule of di-isobutylene, a colorless liquid. This process of joining two or more molecules into a big one is called polymerization.

Di-isobutylene is termed by chemists as unsaturated, which means to say all the hydrogen-hungry bonds of the carbon are not satisfied. By a process called hydrogenation, perfected by the Standard Oil Company, two more hydrogen atoms are hitched to each di-isobutylene molecule. The result is an iso-octane. In hydrogenation of the chemically pure substance, for each 100 bbl of di-isobutylene input, about 102 bbl of iso-octane result. This led to the notion that by some molecular hocus-pocus the law of conservation of matter had been overruled to give more product than raw material. 'Tain't so, of course. The increase comes from the addition of gaseous hydrogen.

Another type of blending agent is codimer. Like the iso-octane just discussed, it is a polymerization and hydrogenation of two refinery gases, isobutylene and normal butylene. A different catalyst is used. The process is important because it does not require so much isobutylene, of which there is quite a dearth.

In 1938, a single-step process, known as alkylation, of arriving at an iso-octane was announced. Like the previous method, it is a way of making "big ones out of little ones." Two gases, butylene and isobutane, produced from natural gas and in refinery operations, are bubbled through a sulphuric- or hydrofluoric-acid catalyst. The product is an alkylate averaging more than 90 octane. It is produced more directly and at considerably lower cost than by the two-step method of polymerization and hydrogenation. In the aviation-fuel program alkylate has provided the largest proportion of all blending agents.

Cumene is another new blending agent. It is produced from benzol (a coal by-product), and petroleum gases. It has an octane rating of over 100, but cannot by itself be used as a fuel. Toluene, produced from coal tar and from petroleum, is another blending agent of high-octane rating. Toluene, however, is valuable in the making of explosives, hence, not much of it can be diverted to aviation fuel.

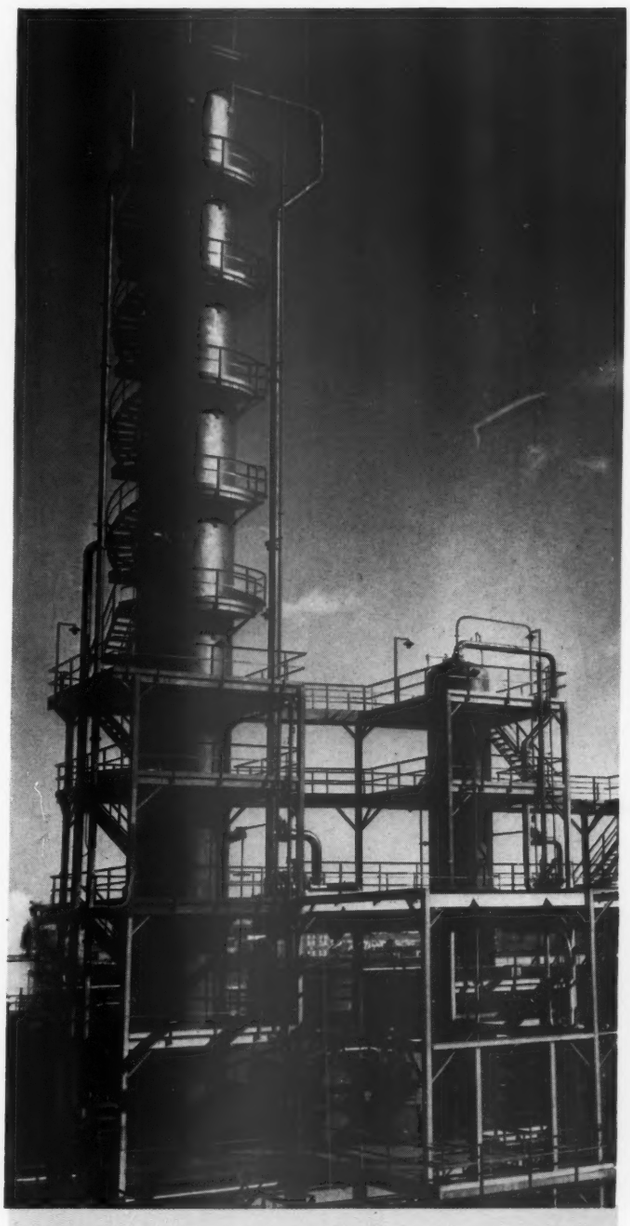
Triptane has received excellent press notices. It, too, is made by combining refinery gases to make a liquid within the boiling-point range of gasoline. It really is a superb blending agent not only because of its high antiknock value, but also because it improves the rich-mixture performance of engines without adversely affecting the lean-mixture characteristics. Adding it and Ethyl to the proper base stock makes a superfuel well above 100-octane number. The cost in the small quantities now made is several dollars a gallon so it will not soon figure strongly as a blending agent.

These aromatic hydrocarbons have much higher ratings when the engine is operating with a rich-mixture ratio, as in take-off, diving, and high-speed pursuit maneuvers, than at the lean mixture used in cruising. They are added to aviation fuel to secure just this effect.

By blending these various agents with straight-run and catalytically cracked base stocks and tetraethyl lead, we have arrived in the United States at a daily production of over 500 000 bbl of aviation fuel of 100 octane and better, plus many thousands of barrels of lower grades. It has been an achievement of the first order of magnitude, built on hard work, technical genius, and the utmost in cooperation within the petroleum industry and by those that serve it.

Now That We Have It!

It seems easy to extrapolate to that time when the last shot has been fired, when Allied bombers have flown their last mission, and gasoline coupons become a memory. With the main technical hurdles in the production of 100-octane

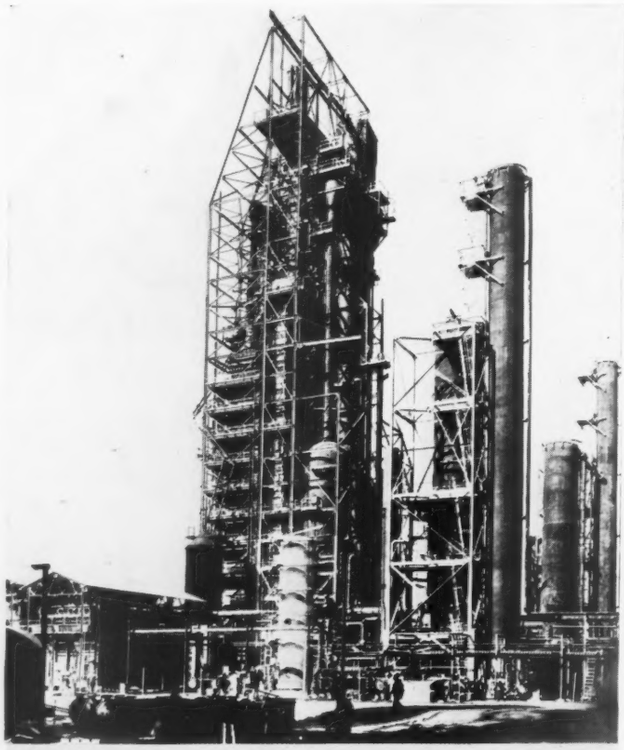


Isobutane, butane, and alkylate come from towers like this for high-octane gasoline blending agents and for synthetic rubber.

fuel successfully passed, can we not logically expect to find much of this miracle fuel diverted from aircraft to automobiles? No!

One fact to consider is simply a matter of quantity. The prewar consumption of gasoline by motorists was about 1 700 000 bbl daily. It appears to be physically impossible to supply anything like this much 100-octane fuel, even if it were economically or nationally desirable, which is definitely another matter. Even by straining every facility, and by degrading motor gasoline, wartime peak production of 100 octane has not quite equaled one third prewar civilian motor-fuel consumption. Furthermore, the production of high-octane fuel will be reduced after the war and not all of it will be available for automobiles.

Aviation fuel has of necessity been made without regard to cost. Some blending agents costing over a dollar a gallon have been used. Blending agents have been produced in some plants and shipped hundreds of miles to other plants. Such practices cannot be justified in normal times. Thus, a portion—amount unknown—of our 500 000-bbl-per-day capacity for 100-octane fuel will of necessity meet with the economic axe. Also, postwar aviation—military, commercial, and private—will require much more of this fuel than before the war. Several educated guesses place the postwar aviation requirement at five times the prewar total, or about 50 000 bbl per day. These factors will, ignoring all others, reduce the practical production of 100-octane fuel for a long time to well under the half-million barrel wartime production, to some small fraction of automotive fuel requirements.



Catalytic plants, such as this Thermofor unit of General Petroleum Corp., make base stock and ingredients for blending agents.

Fuels and engines must go hand in hand. To have a fuel better than engines can use advantageously is as wasteful as to have engines better than the fuel available. There is no compensation in increased economy and performance to offset the higher cost of producing such fuels. The cars on the road now and for some time after the war's close—indeed probably including the first year's production of cars—cannot take full advantage of 100-octane fuels. The 1942-model engines with highest compression ratios (7.25) required fuel no better than 80 octane.

Automobile engines of the future will undoubtedly be designed to use higher octane gasolines. While the day of the 100-octane automobile is likely to be many years distant, wartime experience with aircraft engines and the potential advantages of engine designs freed from the restrictions of knock will give designers no peace of mind until superior engines are achieved.

Much development work lies between here and automobiles with compression ratios of eight or ten, superchargers, smaller rear-axle ratios, and automatic transmissions. It is not simply a matter of modifying aircraft engines for automotive use. Many major differences exist between the two power plants. By comparison with the automobile engine, the airplane engine costs about ten times as much per horsepower. The aviation engine runs virtually at constant speed, enjoys a high load factor, and has a life between overhauls of a fraction of that demanded of automobile power units. Higher compression, supercharging or both, poses severe problems. In prewar automobile engines designed to run on premium fuel, peak pressures developed in the cylinders amounted to about 600 pounds per square inch. Modern aircraft engine cylinders, burning 100-octane fuel without detonation develop peak pressures of 1000 to 1200 pounds. This introduces problems of stiffness of parts, vibration, and the serious one of engine "roughness" and consequent greatly increased engine noise. Noise from engines burning 100 octane fuel is meaningless in a bomber or pursuit airplane, but is far louder than the motorist has been encouraged to expect or would accept. Greater power from given-size engines calls for different bearings, improved cooling, and other alterations in engine construction. Superchargers capable of quiet operation and good output at low engine speeds remain to be developed.

All these obstacles are but hurdles to be gotten over. The engineer, although characteristically grumbling about them, at heart accepts them as challenges. As long as there are about 250 miles theoretically possible from each gallon of gasoline, automotive designers will strive to build better engines that can use a bigger portion of that potential fuel energy. Obviously, the result will be progressive improvement, which means that the octane requirements will rise accordingly.

The consensus of considerable opinion in the petroleum and automotive industry is that the octane ratings of early postwar gasolines will be: aviation, 100 plus; premium, 85 to 88; regular, 78 to 90; and third-grade (if any), 68 to 70. This represents an increase of about four to six octane numbers over the rating of the corresponding prewar fuel.

High-octane fuel (100-octane number or better) is here to stay. The war has greatly hastened its coming, while at the same time has retarded the normal companion development in automotive engines. The sleek, lightweight, supercharged, high compression rear-engine car, giving 40 miles per gallon, is for the future. But, of this much we can be sure, the technology of fuels and engines to burn them, on which so much of victory has rested, can also be counted on to give progressively better transportation in peacetime.

CHARLES A. SCARLOTT

Electronic Oscillograph—Time Microscope

In the study of ultra-high-speed transients, and similar electrical phenomena, that take place in a realm beyond man's ken, a picture is worth many reams of involved computations that are susceptible to errors. The electronic oscillograph provides the portrait from life that tells the history of transients, their rise and fall and—most important—the speed of their passing.

OTTO ACKERMAN AND EDWARD BECK
Protective Devices Engineers
Westinghouse Electric & Mfg. Company

EVENTS sometimes run their course in electric circuits with a swiftness that is far beyond our physical powers of perception. Who can conceive of or describe a millionth of a second? In that time, a point on the earth's equator moves only about 0.02 inch although the earth's surface is moving at a speed of about 16 miles per minute; yet that time is sufficient for a voltage to rise from zero to a million or more and start events that shut down a transmission line and disrupt important manufacturing processes. Twenty years ago, the lack of an instrument capable of measuring these brief intervals and recording what goes on during them seriously impeded progress in electrical-equipment development because the exact nature and effect of electric transients was a closed book. This book was opened by the cathode-ray tube, which years of experience and refinement of design have developed into the present cathode-ray or electronic oscillograph.

The microscope and the electronic oscillograph have much in common. Both make possible the exploration of regions in which the unaided senses are helpless. Based on the early work of Braun and DuFour, and later of Norinder, the oscillograph—like the microscope—has become a widely used instrument. With it, engineers peer into the realm of microtime. By the knowledge so acquired, they improve the reliability of power-transmission and distribution systems and build better transformers, circuit breakers, lightning arresters, and airplane-ignition systems. Without it, airplanes would be less powerful and the present high quality of electric service could be accomplished only with the addition of much material and equipment.

An Industrialized Research Instrument

The electronic oscillograph originally was not intended as a commercial device, but as a research tool in the laboratories where it was needed for exploration of hitherto uncharted fields. The main incentives for its development were: the inability of power-frequency tests to explain the behavior of insulation of equipment in service; the indispensability of surge testing in the development of lightning arresters; the necessity for learning the characteristics of lightning voltages and currents; and the importance of the voltage-recovery process in circuit-interrupting devices. It is also a great time saver, for it can be used to analyze circuits, avoiding laborious calculations. It provides answers free from the errors that may enter into the assumptions upon which calculations of this nature are based.

The electronic oscillograph (shown in Fig. 1), like the magnetic one, writes on a photographic film. But unlike the moving galvanometer element and mirror system, the writing agent is not a light beam but a stream of electrons, from which the device takes its name. This feature gives the oscillograph the ability to respond and write quickly, because the electrons are almost weightless and inertia free. The oscillograph, therefore, reacts immediately to electric or magnetic fields and follows faithfully the fastest known changes.

The production of this nimble electronic pencil requires a source of continuous high voltage applied between two electrodes in a vacuum. The source of the electron stream is a cold cathode, Fig. 2, from which electrons are drawn by the high voltage. They rush toward the anode through which there is a small hole. Some of the electrons pass through this hole, which may be regarded as the source of the electron pencil. As a result of the velocity acquired in the high-voltage field, the electrons that pass through the hole in the anode speed on through the deflecting chamber to the photographic film. They tend to disperse, but by means of magnetic fields

Fig. 1—*The cathode-ray tube and all necessary components of the electronic oscillograph are entirely enclosed in this metal cubicle. All controls are on the front of the oscillograph. The cubicle is built of units mounted on panels that can be removed easily, thereby providing flexibility in circuit layouts. The tube and recording chamber are in the section in front. Mr. Ackerman is adjusting the film.*

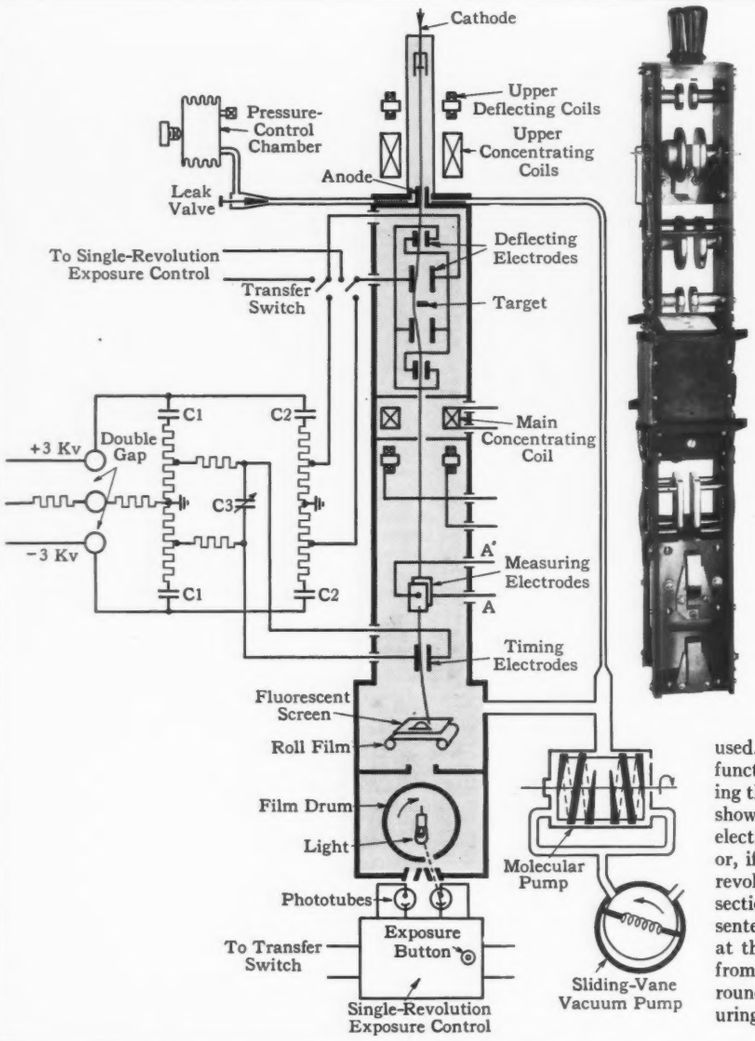


Fig. 2—*Elements of the electronic oscillograph.*

For recording high-speed transients on stationary film, the transfer switch (shown at top left of the cathode-ray tube) is closed in the down position connecting the several deflecting electrodes to the timing system shown at the left. A d-c voltage of three kv is applied to the outer spheres of the double gap, whose spacings are set so that they are just above breakdown at this steady-state condition. The center sphere is normally at ground potential. Any disturbance in the circuit under test, such as the beginning of the surge to be measured, is transmitted to the center sphere through resistance or capacitance coupling. The center sphere is temporarily thrown off ground potential, which makes one of the gaps break down; flashover of the other gap follows immediately as it now is subjected to double voltage. The pair of C_1 capacitors discharges, causing the voltage at C_3 to rise at a definite rate, which in turn produces the time sweep in the oscillograph. At the same instant, voltage is thrown onto the deflecting electrodes of the ray-blocking section by the discharge of capacitor C_2. This bends the beam around the target. The speed and consistency of this process is vividly illustrated by the four records of Fig. 8 on which no variation in timing can be detected. The voltage to be measured is applied at A-A'. The fluorescent screen is used to view the resultant trace as it is made. When this screen is turned sideways the photographic film is uncovered. For phenomena of relatively long duration, film on a rotating drum is used. The movement of the rotating film provides the timing function so the transfer switch is thrown to the left, disconnecting the electrical timing system. Pressing the exposure button, shown below the tube, causes the film to be exposed to the electron beam. This exposure can last for several revolutions; or, if desired, a phototube control limits the exposure to one revolution of the drum. The analogous parts of the control section of the cathode-ray tube shown in the diagram are presented in their true perspective in the photograph. The handles at the top are for convenience in removing the control unit from the tube and are removed after installation. The eight round deflecting electrodes are at the top and the square measuring electrodes are below. The timing electrodes are enclosed.

they can be focused, as a lens focuses light, to impinge on the film in a fine point. This apparatus for forming the electronic scriber is entirely distinct from any of the measuring circuits and devices, and plays no effective part in the measuring except to provide the recording agent.

To obtain records of maximum clarity, the film is in the evacuated chamber so that the electron pencil strikes the film directly. Though it is not light, the beam produces a photographic effect somewhat like an x-ray. The electron beam may move across the film with a speed of some 600 miles a second, yet its path is marked by a sharp, distinct trace.

Speed Requirements Determine Recording Choice

Either of two arrangements of film can be used, depending upon the resolving power in microseconds desired. Where great detail is not required, or where it is desired to record an appreciable interval of time, such as one cycle of 60-cycle voltage, a film fixed on a rotating drum is used. It can be driven at various speeds up to 7000 rpm. A single rotation of the drum gives a record 18 inches long that, at 7000 rpm, represents a time of 9000 microseconds, or 500 microseconds per inch.

For higher recording speeds, i.e., transients lasting only a few microseconds or less, the film cannot be moved fast enough. Instead, a fixed film is used, and the electron beam is given a motion across the film at right angles to the deflection produced by the quantity measured. This is accomplished by passing the beam between a pair of timing plates on its way to the film. A uniformly varying timing voltage is applied to these plates, whose field reacts on the stream of electrons and sweeps it across the film. The voltage is obtained by charging a capacitor through a resistance, and the speed of the timing sweep can be adjusted by changing the constants of this capacitor circuit.

In addition to the film, the oscillograph is equipped with a fluorescent screen that serves the same purpose as a ground-glass plate or finder in a camera. The screen can be manipulated from outside the oscillograph, so that visual observation can be made through a window.

Electrostatic Fields Provide Timing Component

In addition to a writing agent and a means of producing a time coordinate, the oscillograph must have a means of deflecting the pencil at right angles to the timing axis, actuated by the quantity to be measured. Because the electron beam is a current, it can be deflected either by magnetic or electric fields. Magnetic fields drain energy from the circuit under test and introduce appreciable currents in the oscillograph. The electric electrostatic fields used in the electronic oscillograph avoid these undesirable features.

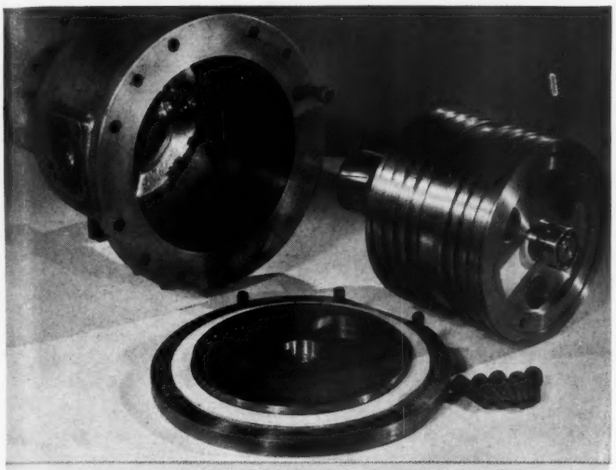


Fig. 3—*These components show the relative simplicity of the little-known molecular pump. The electric motor is built in.*

The grooved cylinder is driven at a speed of nearly 3600 rpm. The leading edges of the grooves of the rotor cut into the rarified air in the center channel and force it towards the cylinder ends. The pump needs no heating-up period, no cooling water or gas trap and is not subject to atmospheric contamination.

Another pair of deflecting plates is arranged at right angles to the timing plates. When voltage is impressed on these plates, the beam, in passing between them, is deflected in proportion to the magnitude of the voltage. The electron beam is thus controlled in one axis by the voltage representing time and in an axis normal to the time axis by the voltage representing the transient.

This completes the electronic camera except for one thing, the shutter. If the beam were allowed to impinge on the film while the oscillograph is waiting for application of the voltage to be measured, the film would fog. Because of the high speed required, a mechanical shutter is out of the question. As in the case of the timing sweep, movement of the beam itself is used to initiate the exposure. As shown in Fig. 2 an obstruction, or target, is placed directly in the normal path of the beam. Thus, when the circuits are at rest, the film is completely shielded. Another series of deflecting plates, above and below the target are so arranged that when they are properly energized the beam is bent around the target and strikes the film.

To operate the oscillograph, the film is loaded, the vacuum and the electron beam are established. When the transient occurs, the beam is bent around the target by means of suitable circuits, the timing circuit is energized, and the measuring plates deflect the beam as the timing sweep carries it across the film. Thus the record is made. All this requires split-microsecond timing.

Certain accessories are required. In the electronic oscillograph all of these necessary adjuncts and the measuring chamber are incorporated in a self-contained cubicle. These accessories include a two-stage vacuum pumping system, a high-voltage rectifier and its controls, the timing-sweep circuit, a high-frequency oscillator for calibrating the timing sweep, a circuit for calibrating the voltage scale, the shutter circuit and means for actuating it in synchronism with the measured voltage, a potentiometer to adjust the voltage scale within convenient limits, magnetic focusing circuits, and the rotating film-drum drive. To place the oscillograph in service requires only that connection be made to the proper power outlets and to the test circuit.

Because some parts inside the cathode-ray tube require periodic cleaning and maintenance, the tube is built so that it can be dismantled quickly by using simple tools. Such maintenance is infrequent and depends on the amount of use. In the impulse laboratories of the Westinghouse Company, where these instruments are in constant use, the cathodes must be repolished about once every three weeks. Grease-sealed cones of vacuum-tight operating mechanisms may require repacking three or four times a year and rubber gaskets may have to be renewed every three years.

A High-Voltage Cold-Cathode Instrument

The source of the electron stream—the cathode—is an aluminum plug a quarter of an inch in diameter, set into a stainless-steel holder whose edge projects beyond the face of the cathode, thereby helping shape the electric field. It is supported on a one-inch glass tube that acts as the envelope for the vacuum, and an electrical insulator. The glass tube also performs another function. On its inside wall charges precipitate, which also play an important part in concentrating the beam to assure that a large portion of the electrons pass through the anode hole. A smaller tube would throttle the beam; a wider one would have a diminished focusing effect. The anode is a silver disc in which there is a small aperture. It is fused to a copper plug set in the heavy upper end of the metal deflecting chamber and is thus adequately cooled by conduction.

A cold cathode and 50 000 volts are used to produce the electron beam in this instrument. A lower cathode voltage would reduce the size and cost of the equipment as is indicated by the widespread use of sealed-off hot-cathode tubes for related applications. However, experience proves that the high-voltage method used in the electronic oscillograph produces the most precise and easily controlled records, least sensitive to laboratory operating conditions. There are several reasons for this. In impulse laboratories, for example, where millions of volts rise and collapse rapidly and where surges of

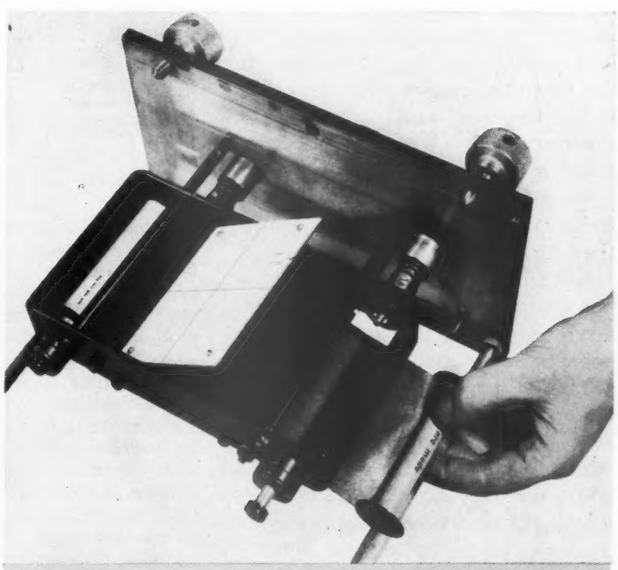


Fig. 4—*This panel assembly that slides from the front of the oscillograph contains the fluorescent screen, here shown as a white plate with cross sections in black, and the roll film holder. The film is loaded here much as in an ordinary camera. Film position is shown by an indicator on the front of the panel.*

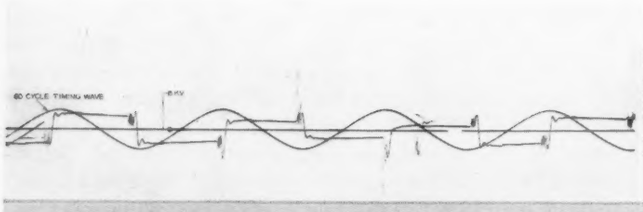


Fig. 5—*A typical example of the kind of trace where the single-revolution exposure is invaluable because of irregular wave form.*

An internal-combustion engine ignition-timing oscillogram made on the rotating film drum using the single-revolution exposure mechanism. Actually, this oscillogram shows three exposures, one each to record the ignition trace, timing wave, and the zero-reference line.

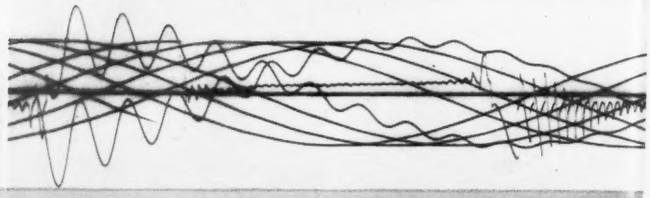


Fig. 6—*A typical oscillogram made on the rotating-film drum with the exposure continuing for several complete revolutions.*

This record shows details of two half cycles of arcing, the subsequent recovery voltage and the sustained power voltage at the terminals of an arc-interrupting device. Traces of consecutive revolutions can be distinguished even though they are superimposed upon each other.

many thousands of amperes are released, conductors that are solidly grounded in the usual sense pick up voltages and may be shocked into oscillation. Magnetic fields permeate space that appears to be well shielded. Spurious voltages may thus appear at the measuring plates and at the cathode that would affect the generation and deflection of the beam. One of the important accomplishments of the electronic oscillograph in impulse testing is the reduction of these outside influences to insignificant values by proper circuit layout shielding and voltage selection. The higher the cathode and deflecting plate voltages, the less the influence of these disturbing factors and the simpler the problems of the technician.

The speed of the electrons in the writing beam, which is a function of the accelerating potential between cathode and anode, is the dominating factor in the calibration of the instrument and in its freedom from disturbances. Just as the course of a high-velocity bullet is less subject to the variable influences of wind and atmosphere, so the high-speed beam is less affected by stray fields. Furthermore, it is desirable to maintain a high ratio between the cathode-to-anode voltage and the voltage on the measuring plates. The reasons for this are as follows. The tangent of the angle to which the beam is deflected by the voltage on the measuring plates is proportional to the measured voltage only if the electron speed is fixed. The electron speed is determined not only by the cathode-to-anode potential, but also by any other electron voltage field in the path of the beam.

The voltages to be measured, which are applied to the deflecting plates, are bound to set up such field components in the path of the electron beam and thereby have an accelerating or retarding effect on the flow of electrons similar to that of a grid in other vacuum tubes. In a device where constant electron speed is essential, it is obvious that the more this effect can be minimized, the better.

The Vacuum and Its Control

The two-stage pumping system, a sliding-vane vacuum pump and a molecular pump (Fig. 3), is capable of evacuating the oscillograph to a pressure lower than is needed for its operation. The establishment of the cathode beam requires a low but definite gas pressure, held within narrow limits, in the discharge tube where it originates. In fact, the beam intensity is controlled by this pressure. In order to attain this required pressure, starting from a hard vacuum, a tiny trickle of air is admitted into the oscillograph tube through a delicate leak valve (Fig. 2). The air could be taken directly from the surrounding atmosphere. However, control of the ambient atmospheric pressure affords an excellent means for fine regulation of the air flow through the valve. For this reason, air is fed to the valve from a bellows chamber whose volume and pressure can be controlled manually to within plus or minus 20 percent of atmospheric pressure.

During closely scheduled testing, the oscillograph body may be opened to the atmosphere several times an hour for reloading with film. The pumping system can evacuate the instrument to operating pressure within about seven minutes, even though in the chamber there are porous and gas-absorbing materials such as coils, the stator winding of the film-driving motor if used, and the film itself. The water vapor taken up by these materials would interfere with the evacuation, hence provision is made to introduce phosphorus pentoxide, a most effective dehydrator, into the oscillograph below the film holder.

The electronic cathode-ray oscillograph and the a-c calculating board apparently have little in common. The theory, operation, and purpose of these two intricate electrical devices are entirely dissimilar. Yet, together, they are the means of solving problems that could not be resolved in any other way. The a-c calculating board (described on p. 111 in the last issue) is comprised of a voltage source and units of resistance, inductance, and capacitance. These elements can be arranged in circuits simulating in miniature those of actual circuits, enabling the electrical values to be metered conveniently. In this manner, problems arising from involved circuits are answered. To determine the transient reactions of circuit components to surges, such as arrester requirements for lightning protection of rotating machines, (March, 1944, p. 60) it is necessary only to impress a surge of the desired character on the artificial system and record the voltages at the points in question with the electronic oscillograph. The precise surge reaction is discovered with comparatively little effort and without risk of errors which so readily creep into involved calculations of this type.

Synchronization Is Exact

The matter of synchronizing the film exposure and the beginning of the time sweep with the phenomenon to be measured is of prime importance. The basic circuits performing this function are shown in Fig. 2. With stationary film, Fig. 4, time sweeps of from one half to 20 000 microseconds are had by the proper selection of resistors and capacitors in the sweep-control circuit. For this purpose a number of different resistance and capacity branches are built into the instrument and can be selected by sets of switches. A time axis about three inches in length is thus provided.

If more extended records are desired, the rotating film drum is used. By this, the film is moved under the

electron beam, and the timing circuits used with stationary film are inactive. The shutter scheme, described previously, is still used, however, and serves to expose the film for any desired length of time. It can be combined with a photoelectric circuit to start the exposure and cut it off at the end of the film. This is a feature, invented as a result of the inconvenience occasioned by the difficulty in unscrambling intricate traces superimposed on each other because the recording continued for several revolutions of the drum. It produces a film that is easily read, having but the single trace with no confusing overlapping. Certain traces, simpler in form, are carried through several revolutions of the drum to secure the record of a relatively long-time operation, or a series of operations.

Typical Uses of the Electronic Oscillograph

The various methods of recording transients described above have been developed to meet the requirements of the manifold applications of the electronic oscillograph. Among the principal fields in which the electronic oscillograph is uniquely valuable are the following:

(a) The recording of electrical disturbances caused by natural lightning.

(b) The determination of breakdown characteristics and coordination of the insulation of all kinds of electric-power equipment.

(c) The development and testing of lightning protective devices.

(d) The development and testing of circuit-interrupting devices, principally through the recording of the speed with which such apparatus recovers its insulating properties while opening a circuit.

(e) Study of all types of electric-spark phenomena such as found in combustion-engine ignition systems.

(f) The study of voltage surges, traveling waves, and voltage distribution in apparatus of various kinds or combinations of apparatus such as a complete station equipment.

Examination of the various types of records obtained with the electronic oscillograph illustrates the character of the information obtained through it. Figure 5, for instance, shows the magneto voltage of a combustion engine. Details in the sharply peaked spark voltages are of interest to the ignition specialist, and even a casual observation discloses that the various cycles are not very uniform either in wave shape or duration. This has a bearing on engine efficiency. The record was taken on the rotating-drum film, which was exposed for one revolution to register the ignition voltage. Two subsequent exposures provided a zero line and the 60-cycle wave for timing purposes.

In testing circuit-interrupting devices, film-drum records extending over several revolutions are desirable. The various cycles in an arc-interruption process differ sufficiently from one another to be discriminated even though the traces do overlap. This type of record, Fig. 6, can cover a relatively long time interval.

At the other end of the time range of the electronic oscillograph are records registering clearly an event taking place in a fraction of a microsecond such as shown in Figs. 7 and 8. Such records are taken on stationary film. In Fig. 7, several exposures are taken within a short space of the film, the latter being moved a fraction of a frame for each exposure. In Fig. 8, the film was not moved at all between exposures. Four distinctly different traces were anticipated by the operator; therefore all of the traces were placed on the same time axis which helped in the comparative analysis of the four distinct events depicted on the same frame of oscillographic film.

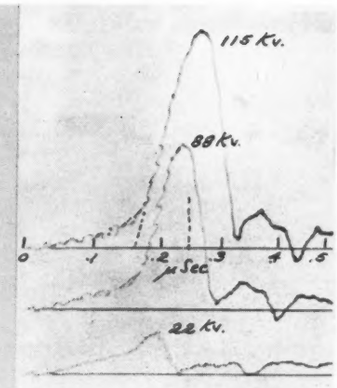


Fig. 7—*An oscillographic record of the puncture of a solid insulation sheet.*

The first trace shows an outside flashover of the insulation barrier at 115 kv, accomplished within 0.3 microsecond. In the second exposure, the barrier punctured at 88 kv. The insulation is pierced at 22 kv in the next discharge. This series of traces illustrates the economy afforded by advancing the film only a portion of a frame after each exposure.

Timing Consistency Within 10^{-8} Seconds

A surprising feature of oscillograms of this type is the consistency with which the oscillograph starts its time sweep with respect to the measured phenomenon. The rise of each surge voltage recorded and the start of the time sweep in the instrument are distinctly separate events occurring at places remote from each other, coupled only by electrostatic means and involving the breakdown of several sphere gaps. Yet, this timing repeats itself within one hundredth of a millionth of a second. If there were variations larger than this, they would manifest themselves by a discriminable shift in the starting point of the various wave fronts. The inclination has been to picture such events as random phenomena in which an appreciable variation might be expected. However the electronic oscillograph shows an uncanny degree of consistency in timing. This unbelievable astuteness, combined with accuracy and ease of operation, makes this device the essential instrument in the field of analyzing ultra-high-speed phenomena.

Figure 8 illustrates how the voltage required to produce a sparkover or puncture depends on the time for which it is applied. The shorter the time of application, the higher is the voltage that the insulation will withstand. This behavior cannot be detected by 60-cycle tests. The familiar time-lag curves of insulators and gaps are a summary of such oscillographic test data. A curve drawn through the maximum points in Fig. 8 is in effect a time-lag curve. Perhaps the most important contribution of the electronic oscillograph to the power industry has been the determination of these curves. Through them the weakest links in the chain of insulation of a system are disclosed by comparing the time-lag curves of the various types of insulation involved. With such information, coordination of insulation can be accomplished and proper protective devices can be selected.

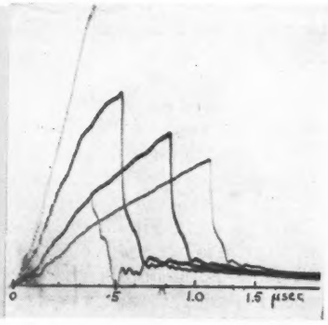


Fig. 8—*Measuring time to spark over on a protective device, using four voltage rates rise.*

Measuring Dielectric Properties at Ultra-High Frequencies

A CYLINDRICAL re-entrant resonant cavity! Relatively few engineers have ever heard the term, much less are able to place it in the engineering scheme of things. This is natural enough. It was born only a half dozen years ago in the ultra-high frequency or radiation laboratories. Yet, indicative of the swift pace of modern engineering, it is moving out of the laboratory and into the factory. It is on the verge of becoming a production tool, much as the mass spectrometer, the x-ray, the spectrograph, and others. Developed by Mr. C. W. Works, Dr. T. W. Dakin and Dr. F. W. Boggs for testing dielectrics at ultra-high frequencies, the operation of this precision instrument is so simple that it lends itself to routine production-line testing for dielectric-constant and power-factor checking in the frequency range 100-1000 megacycles.

Power engineers for the most part think in terms of the standard 60-cycle frequency where a quarter wavelength is 775 miles. It is obvious that at frequencies measured in the hundreds of megacycles, where a quarter wavelength is a matter of inches (about ten inches at 300 megacycles) a rather considerable revision of thinking is required in evaluating circuit constants, the performance of insulation materials and even the characteristics of the current itself.

Actually, the cylindrical re-entrant resonant cavity is simply the equivalent of a coil and capacitor combination coupled to a source of high-frequency current and designed to resonate at ultra-high frequencies. At high frequencies, particularly those upwards of 50 megacycles, where circuit elements become appreciable in size compared to the wavelength, the residual connection-lead and electrode inductance, resistance, and capacitance of the usual coil and capacitor critically affect their performance. The resonant cavity has the same components of a resonant circuit—inductance and capacitance—but in a new guise. The logical progression from the coil-capacitor system to the resonant cavity is shown in Fig. 1. Also shown is a cross-section view of the dielectric-testing cavity. In considering this as an oscillatory system, it is important to keep in mind the skin effect of currents at these frequencies. (The penetration of the current in the conductor at 300 megacycles is but about one and one-half ten-thousandths of an inch.) The cavity, when in resonance, has in effect a quarter wavelength standing along the interior of the enclosure, the voltage maximum loop at one end and current maximum loop at the other. The cavity is energized through an exciting loop, which is fed by an ultra-high-frequency generator through a coaxial cable. To insure that the frequency of the generator is not changed by the necessary tuning of the resonant cavity, the losses in the coaxial cable connecting them are purposely high so that the load imposed by the cavity is but a small portion of the total load on the generator.

The ultra-high-frequency generator in the foreground drives the re-entrant resonant cavity that Dr. Dakin is adjusting. A differential screw enables electrode displacement of 1/240000 inch to be read on the vernier.

The relatively few schemes for measuring dielectric characteristics at high frequencies in this range fall down from a practical standpoint because of the difficulty of getting a solid sample of the dielectric to conform to the shape of the measuring device. In the resonant-cavity method, no difficult problem of specimen machining is presented. All that is required is a sample piece in the form of a disc with plane surfaces parallel.

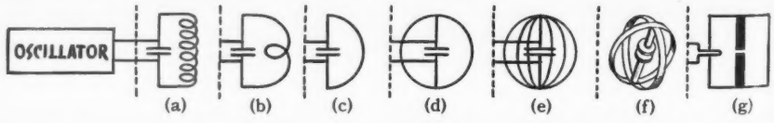
In brief, the test operation is performed in two steps. The dielectric test piece is placed between the electrodes in the resonant cavity and the system brought into resonance, by adjusting the frequency of the oscillator. Readings of the voltage in the cavity on a suitable meter are noted. The dielectric sample is removed and the cavity again brought into resonance and the resultant voltage reading noted. Thus, in effect, a comparison is secured between the characteristics of the dielectric under test and those of air which is, within ionization limits, the standard.

Actually, there are several ways in which these readings can be made. The simplest is the voltage method which gives the loss angle (tan δ) within ± 0.00005 and the dielectric constant in routine tests within ± 1.0 percent. (The angle δ, whose tangent is generally used in high-frequency insulation research, is the vectorial complement of the phase angle θ whose cosine is the power factor more commonly considered by engineers.) A detector probe that extends into the cavity picks up a voltage from the enclosed field. This voltage is rectified by a full-wave crystal rectifier and the resultant average direct current measured by a galvanometer.

The sensitivity of an oscillatory system in the region between 50 and 1000 megacycles is highly important as the quantities dealt with are minute. The sensitivity of the re-entrant cavity is so great that very small adjustments result in large changes in resonant frequency. Therefore, the vernier adjustment of the resonant cavity operates on a differential-screw principle and 1/2000 turn, read on the vernier, is equivalent to a displacement of the capacitor electrode of 1/240 000 inch.

Fig. 1—*The staid, time-tried components of an electric oscillatory system progress step by step in a logical transition to the cylindrical re-entrant resonant cavity here described.*

In this series of sketches the resonant circuit evolves from the usual multi-turn coil and capacitor in (a) to the single-turn coil in (b) and the half-turn coil in (c). Each step carries the system higher in resonant frequency, assuming the dimensions remain comparable. In (d), two half turns have been connected across the capacitor. The number of turns in (e) has been increased. Sketch (f), wherein the inductances about the capacitance are flat strips, shows how a projection of the number of half turns results in complete enclosure of the capacitor. Sketch (g) is the resultant resonant cavity.



Research—A Chore

RESEARCH is not all peering into glamorous new worlds, evolving new theories, developing materials of earth-shaking import. Much of it is steady, tedious, hard work; testing, checking, evaluating; each step, each operation conducted with meticulous care to include all possible related functions. The data thus evolved must be correlated and assembled (or translated into other forms) so that the information is in usable shape. Inquisitive genius points the direction, but statistical information paves the way of organized research.

In such work are Miss Elizabeth McDowell and Mr. W. H. Gard engaged in the mechanics section of the Westinghouse Research Laboratories. Micarta is here subjected to a flexure test at −50 degrees C. This temperature level is achieved by a mixture of dry ice and alcohol. Not only flexing tests, but tests of tension, compression, and shear are conducted under ambient conditions from −50 degrees C to 200 degrees C. Why? Micarta has characteristics that make it valuable for aircraft use: lightness, strength, less critical materials, etc. However, in a plane, this material may be subjected to extreme tropical heat and, within a relatively few minutes, to the frigid temperatures of the stratosphere. What of the Micarta in the all-important control-cable pulleys? Will it stand up under these violent ambient changes? The design engineer looks at the curves resulting from many research man-hours and finds that Micarta actually increases in compression strength at −50 degrees C and that the tension, flexure, shear, fatigue, and many other characteristics meet the requirements of the application. The part is designed with assurance of performance because research has done its chore.

Miss McDowell and Mr. Gard give Micarta a flexure test at −50 degrees C.

The arc being struck by Miss Julia Senko of the Research Laboratories in the spectograph results in a plate such as shown in the inset. By comparing with the spectogram of pure iron, on which the wavelengths of the iron bands in the spectrum have been noted, the wavelengths of the bands in the spectrum of the substance under consideration are accurately established.

Iron to Burn

EACH YEAR about half a ton of iron, 99.99 percent metallically pure, is produced under the supervision of Dr. T. D. Yensen in the Westinghouse Research Laboratories. Every precaution is taken, every facility known to science is used to insure this degree of purity. All to the end result of destroying this iron in an electric arc for making spectroscopy standards.

The multitude of alloys, both ferrous and non-ferrous, now in use requires a swift, accurate means of making qualitative and quantitative measurements of traces of alloying metals or impurities in a sample. To this end the spectrograph has been lifted from the laboratories of the optical physicist and pressed into industrial service. With it, the spectral lines, characteristic of a given metal, are made evident when the element is subjected to an electric spark or an electric arc.

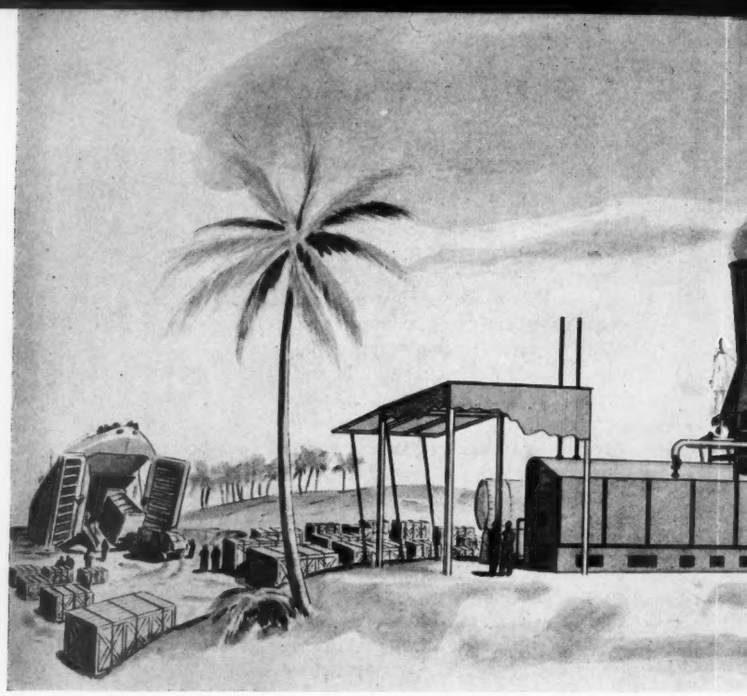
These spectral lines are as individual as fingerprints and are as easily identified. Each line in the spectrum of an element is an indication of radiated energy given off by displaced electrons returning to their proper shell in the atomic structure. These radiations are always of the same wave length for a given element and the same element always produces the same pattern of spectral lines. These lines for most substances have been identified and established. Thus if some unknown lines are found to be of a certain wave length, the substance generally can be readily identified. To identify the wavelength, a standard spectrum is needed.

Iron is an element peculiarly suited for use in establishing a standard for spectroscopy studies. The spectrum of iron contains many lines (306 iron lines have been established by the International Astronomical Union as secondary standards) and these lines are widely dispersed so that the pattern of the iron lines in the spectrum affords many reference points for wavelength calibration.

To produce this iron, it is first deposited electrolytically on a lead anode. In this form, it is apt to be spongy in texture. The spongy iron is reduced to a molten mass in a high-frequency induction furnace, under the protection of a hydrogen atmosphere. Water vapor, free oxygen, and carbon impurities are largely removed from the molten iron by the hydrogen gas. The resulting iron contains total metallic impurities of less than one part in 10 000. The iron is cast into ingots, forged into billets, hot-rolled into rods, and after pickling, the rods are cold drawn and finally ground to size.

These pencil-like rods are used as spectrograph-arc electrodes by companies in various industries (and agencies such as the FBI) for making standard spectrograms. While of particular usefulness to steel companies for quality control, these spectrograms of pure iron are invaluable also to manufacturers of other metals.

This steam-electric power plant is made as a train of eight cars with a total floor area of about 400 sq ft. Two cars, equipped with bent-tube water-wall boilers and locomotive-type stokers designed to burn lignite coal, deliver 80 000 lb of steam per hour at 600-lb-per-sq-in. pressure, 750 degrees F total temperature at the turbine car, which contains a 5000-kw turbine generator, switchgear equipment, transformers, and an auxiliary power unit. Two air-cooled condenser cars, each having 45 000 sq ft of condensing surface, are capable of condensing the exhaust at 2-lb-per-sq-in. gauge pressure, with air temperatures up to 95 degrees F. An auxiliary car, a feed-water make-up car, and a crew car including bunks and repair-shop facilities, complete the train. In addition to the 5000-kw train, there is a 1000-kw power train designed for similar service. This smaller unit (not shown) is comprised of two cars, plus an optional cooling-tower car. The turbine car, in addition to the main generating and switchgear equipment, carries a surface condenser. In locations where circulating water is abundant, connections can be made directly to these condensers. A cooling-tower car with a circulating water pump is supplied for locations where condensing water must be conserved.

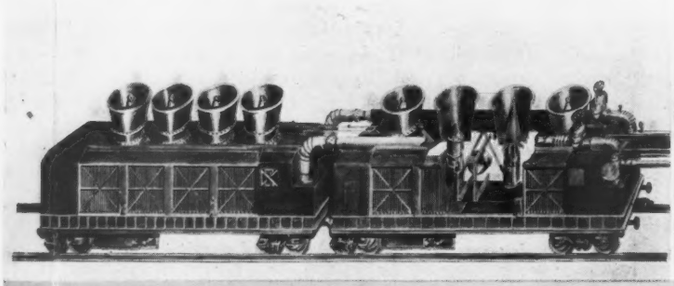


Stand-In for the Ce

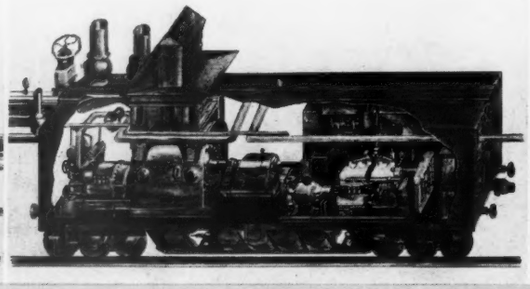
A prime objective of any scorched-earth operation by a re station. When the lights go on again, when industry again fl will be with the aid of mobile or portable power equipment

J. R. BEJARANO, *Mgr., Special Projects Dept., Westin*

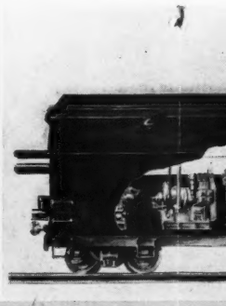
TRANSPORTABLE electric power plants of large capacity are an important weapon of modern warfare. Such plants, capable of being moved as units from one location to another and placed in operation within a short time after arrival at a site, are a direct outgrowth of the strategies of movement and aerial penetration. Numerous areas of land, evacuated or reconquered, must be rapidly prepared to meet the immediate power demand of moving armies for tank, plane and transport repair stations, machine shops, illumination and water supply. Munitions factories, ravaged or relocated out of reach of the enemy, must be quickly restored to operation to provide support for the military. Barren islets from the tropics to the arctics, serenely distant for ages, suddenly become stepping stones and teeming centers of mechanized onslaught. And always, day and night, wheels must turn in defiance of the enemy's attempts to destroy, wheels to implement armies of engines and steel, wheels to spin the hundred needs of a people at war. For all this is needed contin-



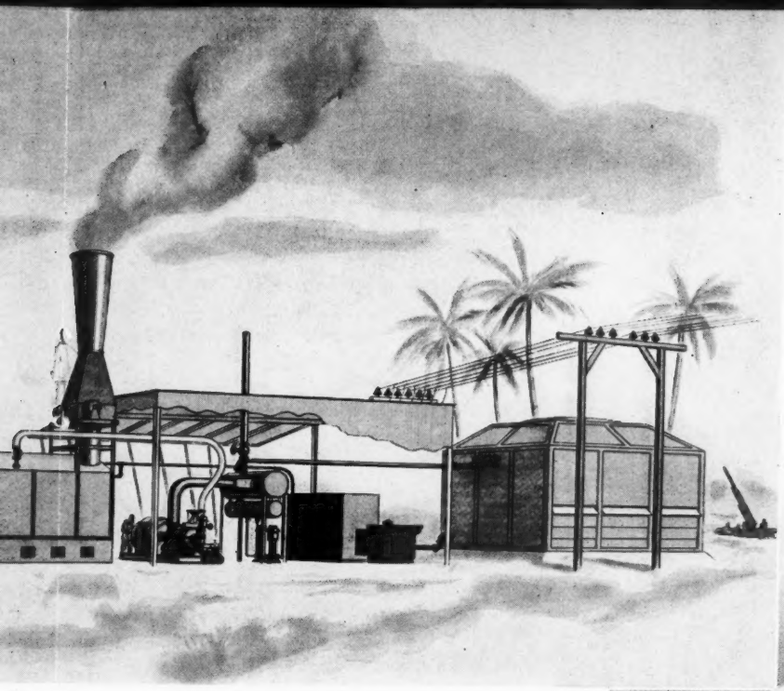
Two air-cooled condenser cars.



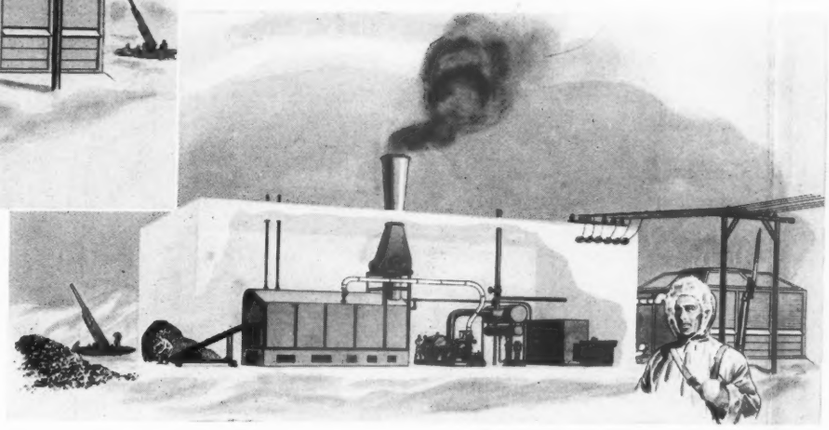
5000-Kw turbine-generator car.



Auxiliary-e



This packaged steam electric plant is made up of approximately 25 preassembled units or "packages" mounted on skids. The boiler can be adapted for oil, coal or wood burning. Another unit comprises the turbine and associated equipment. The cooling tower is the third unit. All of the preassembled packaged units are dimensionally designed to be readily transportable by train, ship or tank-retriever trailer and require minimum time and equipment for assembly at the site, whether it is to be located in the tropics or the arctic.



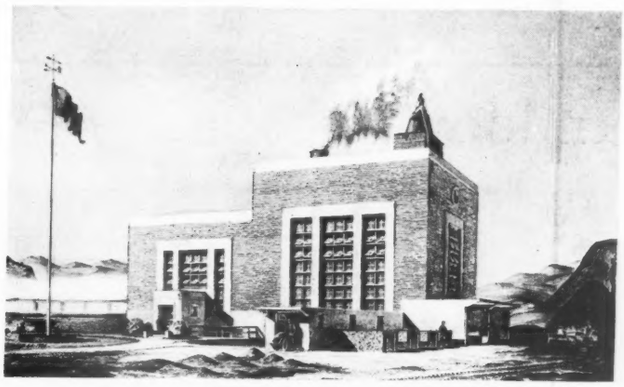
Central Station

by a retreating army is the local electric-power again flexes its electrical sinews, in many cases, it uipment of which several varieties are shown here.

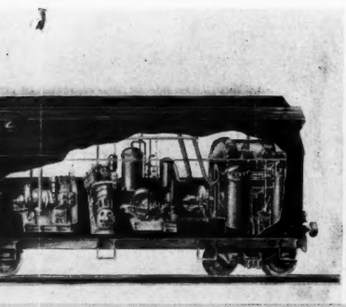
t., Westinghouse Electric International Co.

uous electric power, life blood of an industrial age, plasma for the wounded machine.

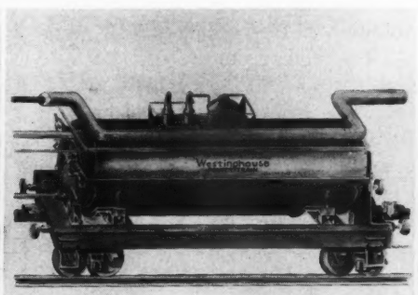
Portable diesel and steam power plants of comparatively small capacity have proved insufficient to meet these requirements in present warfare. First, the limitations of capacity were a serious obstacle; second, the need of combat forces for oil, and the difficulties of transporting high-grade fuel over long distances, make it desirable that larger capacity plants burn lower grade fuels locally available. With these factors in mind and considering the restriction of weights and dimensions imposed by transportation and loading facilities, Westinghouse has developed a series of transportable power plants within these limits. These include the power-train, a railway-car mounted steam electric power plant, the semi-portable power plant, a packaged generating station made up of preassembled units mounted on skids, and the unit power plant, a complete generating station for semi-permanent installation, all parts of which are transportable by truck.



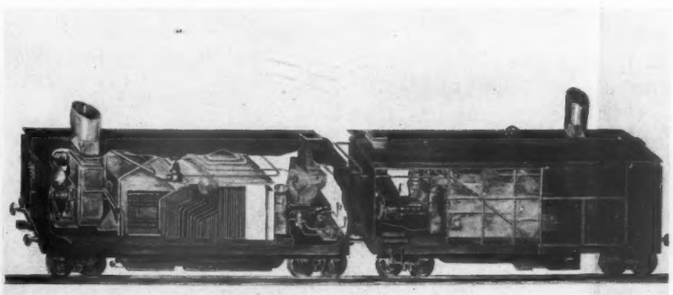
This steam-electric power station has been designed so that it can be readily disassembled and moved to another location. Designed in answer to a specific problem presented by the Chinese Government, it will burn the lowest grade fuels and requires a minimum amount of maintenance. All parts are such that they can readily be transported by truck. Complete instructions for the installation of the equipment, as well as for the construction of the building and associated work, form part of these power plants that now are available in "kit" form.



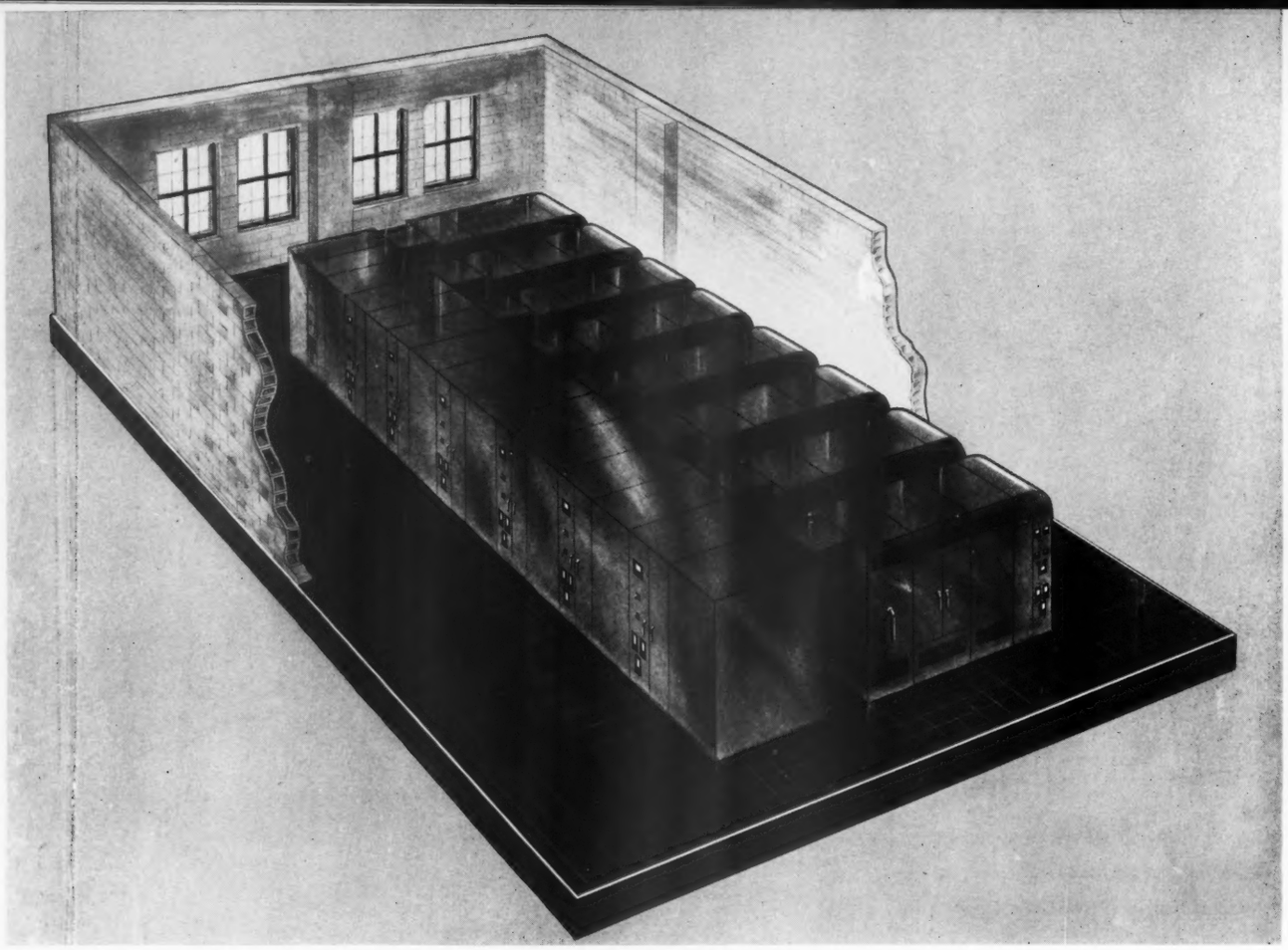
uxiliary-equipment car.



Tank car for feed-water make-up.



Two cars with bent-tube, water-wall boilers.



Indoor Substation—Completely Air Cooled

Specific answers to specific problems, that's what realistic planning must be. In this direction, an article in the last issue* suggested numerous power-system economies that can result by modifying distribution practices to capitalize on the 20-year accumulation of apparatus improvements. The article here and the two that follow it get down to specific cases—discussing in considerable detail the simplified, completely air-cooled-equipped distribution substation in its several possible combinations.

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Distribution Engineer
Westinghouse Electric & Mfg. Co.

INDOOR substations, like other major apparatus, cannot be basically changed in design to accommodate every improvement in some component. But, sooner or later, the accumulation of those improvements, large and small, piles up to such an impressive total that they justify major overhaul of design, with resulting substantial economies or improved performance. The developments relating to distribution substations, particularly those hinged on air cooling, plus standardization in transformers and switchgear, make an impressive total that can be utilized to advantage.

One type of modernized, simplified indoor substation, having a firm capacity rating of 16 000 kva and using only air-cooled and air-insulated apparatus, is shown in Fig. 1. The station's 13.2-kv bus is supplied by four subtransmission circuits, any three of which can carry the entire load. The 13.2-kv bus is in four sections, joined by three bus-tie breakers. Each of the four supply circuits is connected to a bus section through a breaker. The station is normally operated with the bus closed and all subtransmission supply circuits in service, that is, with all seven high-voltage breakers closed.

Beyond the high-voltage bus the station is designed on a 4-kv feeder-unit basis. Each feeder unit consists of a three-phase, air-cooled transformer with a magnetizing current break switch on its 13.2-kv side and a distribution-feeder circuit breaker on its 4-kv side. The switch is so interlocked with the breaker that it can be moved only when the breaker is open. Three-phase voltage regulation of the feeder is provided by tap-changing-under-load equipment built into the transformer.

Two feeder units are connected to each high-voltage bus section through the switches on the 13.2-kv side of the transformers. No high-voltage transformer breakers are used. Because a high-voltage bus section and two transformers are operated as a unit without automatic protection between them, a transformer fault is cleared by tripping the supply circuit breaker and the bus-tie breaker (or breakers) connected to its associated bus section. This interrupts service on the two 4-kv feeders associated with the de-energized bus section. Service can be restored quickly to the feeder whose

*"Modern Equipment Aids System Savings," A. C. Monteith, *Westinghouse ENGINEER*, September 1944, p. 147.

transformer is not in trouble, however, by isolating the defective transformer and reclosing the high-voltage supply and bus-tie breakers. The faulted transformer can be isolated by tripping its 4-kv feeder breaker and opening its connection to the high-voltage bus.

A high-voltage breaker with each transformer would prevent interrupting service on more than one 4-kv feeder when a transformer fault occurred. However, failures in modern transformers are extremely infrequent. Also, service to the good feeder unit affected by such a fault can be restored easily. Therefore, high-voltage transformer breakers are not deemed justified.

Feeder faults beyond the transformers are cleared by the 4-kv feeder breakers. There is no 4-kv bus in the substation. Because the transformers are not operated in parallel, the interrupting duty on the 4-kv feeder breakers is small and is constant regardless of the number of transformers and feeders.

Relatively large substations such as this on radial distribution systems require exterior facilities for switching the load of any one 4-kv feeder onto two or more adjacent feeders so as to restore service quickly following a feeder failure. Adequate capacity is provided in the station of Fig. 1 to permit this by using automatic air blast on all transformers. Because these switching facilities must be available elsewhere in the system, even a 4-kv transfer bus has been omitted from the substation; and these external switches are utilized when it is necessary to take a substation transformer out of service for maintenance or repair. All circuit breakers in the station are air breakers of the metal-clad, draw-out type. Thus, by providing one spare 13.2-kv and one spare 4-kv breaker, any breaker can be serviced by withdrawing it from its compartment and inserting the spare in its place. The various circuits and bus sections can be grounded by a portable device, which can be inserted in any circuit-breaker compartment when the breaker is removed, to ground either the supply or load terminals in the compartment.

The appearance of the substation equipment when installed

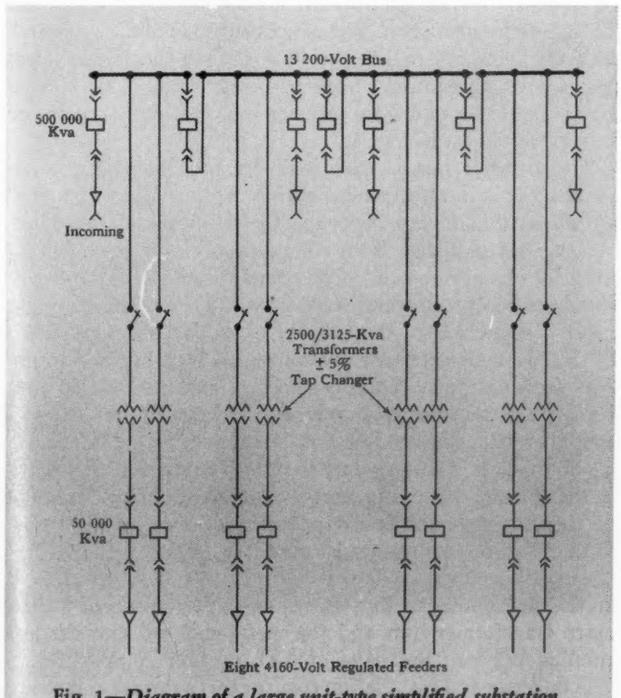


Fig. 1—*Diagram of a large unit-type simplified substation.*

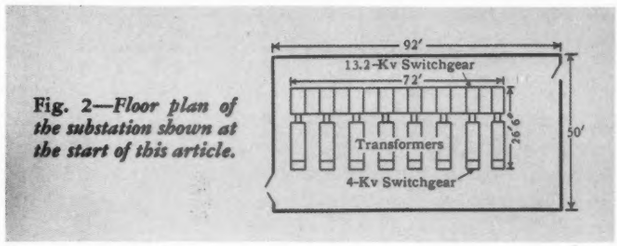


Fig. 2—*Floor plan of the substation shown at the start of this article.*

in a building is shown on page 178. The 13.2-kv metal-clad switchgear, with air circuit breakers, extends across the front of the building. To it are bolted eight duplicate feeder units, each consisting of an air-cooled transformer for automatic tap changing under load and a 4-kv air circuit breaker. Use of dry-type transformers enables all equipment to be installed indoors safely. This makes unit construction possible, in which all connections between the different pieces of equipment are made with short sections of metal-enclosed, insulated, copper bus. The necessary protective and control equipment is mounted and wired integral with its associated switchgear units.

Many potheads, cables, and conduits, required when oil-cooled transformers are used outside the substation proper, are eliminated. Air-insulated equipment of unit construction can be installed simply by placing the units in position, bolting them together, and connecting the four 13.2-kv cable circuits and eight 4-kv cable circuits to their associated switchgear compartments. The units are relatively small and light in weight so that means for handling very heavy pieces is not required. A plain floor, free from conduits and cables, except for the four incoming and eight outgoing circuits, can be used. No basement is required. Provisions for minimizing the hazards of oil fires are unnecessary. All this means an appreciable saving of time and expense for building construction and equipment installation.

Locating all substation equipment indoors improves station appearance and eliminates criticisms resulting from noise. The question as to the size of the building required for such a substation naturally arises. As shown in the floor plan, Fig. 2, a building 92 feet wide and 50 feet deep, or 4600 square feet, is adequate, leaving ample space for maintenance work and movement of the equipment into and out of the building. The maximum height of the equipment is 9 feet 2 inches. The building height, therefore, is fixed largely by appearance and the necessity for providing adequate natural ventilation. The cost of the electrical equipment for the substation just described is $179 000 or $11.19 per kva of firm demand at the station terminals.

To obtain a true evaluation of the proposed substation equipped with all air-insulated apparatus, a comparison should be made with a substation of similar size but of more conventional design, Fig. 3. This station is arranged to take maximum advantage of standardized, modern equipment. The 13.2-kv supply circuits and bus are the same as in the station of Fig. 1. A 4000-kva, oil-insulated transformer equipped with automatic air blast to give 5333 kva is connected through a circuit breaker to each of the four 13.2-kv bus sections. These four transformers are connected through breakers to the four sections of the 4-kv bus. Both the 13.2-kv and 4-kv buses are normally closed. Two 4-kv distribution feeders are supplied from each low-voltage bus section through feeder breakers.

Individual feeder regulation is obtained by an air-cooled triplex regulator in each feeder. A reactor is located in each

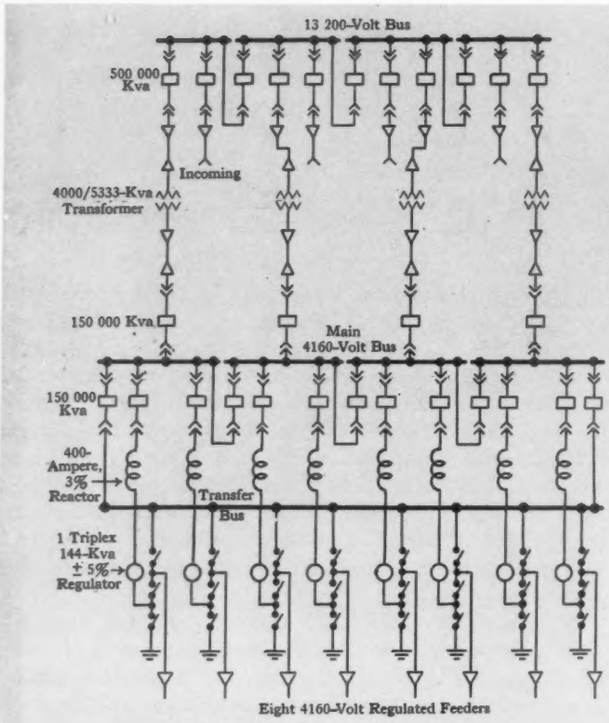


Fig. 3—*Diagram of conventional-type substation designed to use modern metal-clad equipment.*

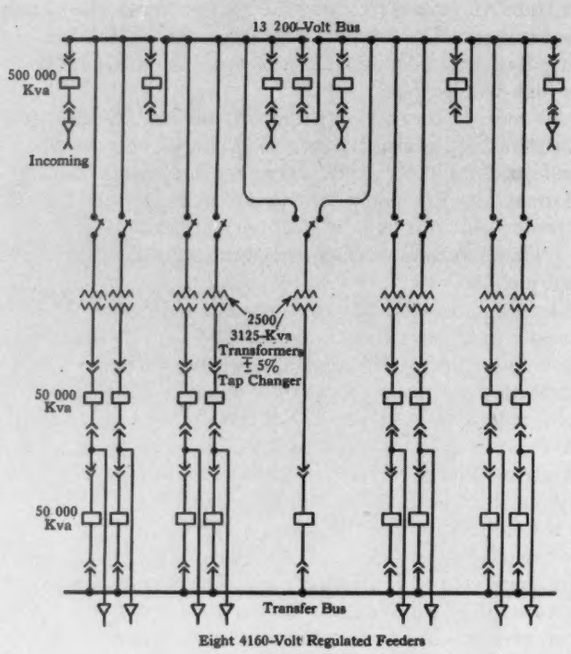


Fig. 4—*Diagram of a large unit-type substation modified to facilitate maintenance of equipment.*

feeder between the regulator and the feeder breaker to limit the fault current through the regulator to a safe figure and to permit the use of 100 000-kva interrupting-capacity feeder breakers. A 4-kv transfer bus and the necessary disconnecting switches permit de-energizing the regulators for maintenance or repair without dropping load or switching circuits outside the station. The transfer bus can be energized through tie breakers connecting it to the two end sections of the main 4-kv bus, and thus it can be used to tie these two sections together, making a ring bus of the main bus.

Air circuit breakers of the draw-out type are used. All switchgear, buses, and regulating equipment are metal clad and are located indoors. The four power transformers are located outdoors. The minimum amount of cable and conduit work and the best appearance are obtained when the 13.2-kv switchgear is located in one building and the 4-kv switchgear and regulating equipment are located in a second building with the transformers in an open court between them. All switchgear and regulating equipment can, however, be located in a single larger building with the transformers outdoors behind the building. In any case, the station requires 3866 square feet of floor area indoors and about 1890 square feet outdoors. The total station area is 5756 square feet, or one fourth more than required for the station of Fig. 1. These figures assume the feeder reactors will be housed in a basement that may extend under the whole building or only under the portion of the building containing the 4-kv equipment. If these reactors are located on the ground floor with the other equipment, the station area becomes 4370 square feet indoors, and the total area, 6260 square feet. The station then requires 36 percent more area than the station of Fig. 1.

The land, building, and installation costs of the conventional substation of Fig. 3 are appreciably more than for the unit-type station of Fig. 1, using all air equipment. The cost of the electrical equipment for the substation of Fig. 3 is $208 000 or $13.00 per kva of firm demand at the station. This is $29 000 or 16.2 percent more than the cost of the substation of Fig. 1.

The transformers and voltage-regulating equipment in the substation of Fig. 1 cannot be as conveniently de-energized for maintenance without dropping load as with the substation of Fig. 3. This is because, as has been pointed out, load must be switched outside the substation from one feeder to others. The air-type substation can be modified to eliminate need for load switching external to the station when the transformers and regulating equipment are to be serviced. This is done by the addition of a 4-kv transfer bus and one more transformer, as shown in Fig. 4.

The transfer bus is energized through the extra transformer. This transformer is provided with a 13.2-kv selector switch so that it can be connected to either of two high-voltage bus sections. Two compartments are provided for each 4-kv feeder breaker. One compartment is connected to its associated transformer secondary and the other compartment is connected to the transfer bus. The other terminals of the two compartments are connected together and to the 4-kv feeder circuit. A feeder can be transferred easily from its normal transformer supply to the transfer bus without dropping load, so as to free the transformer for maintenance. To do this it is necessary only to insert the spare 4-kv breaker in the transfer bus compartment, close the breaker, and then trip and remove the feeder breaker adjacent to the transformer. This frees the transformer for servicing.

The arrangement and appearance of the equipment in this station are similar to that shown on page 178 except for the extra transformer unit and the metal-enclosed transfer bus running between the pairs of 4-kv breaker compartments. The building and installation cost for this substation is somewhat greater than for the substation of Fig. 1 because of the extra transformer unit. No extra depth or height are required,

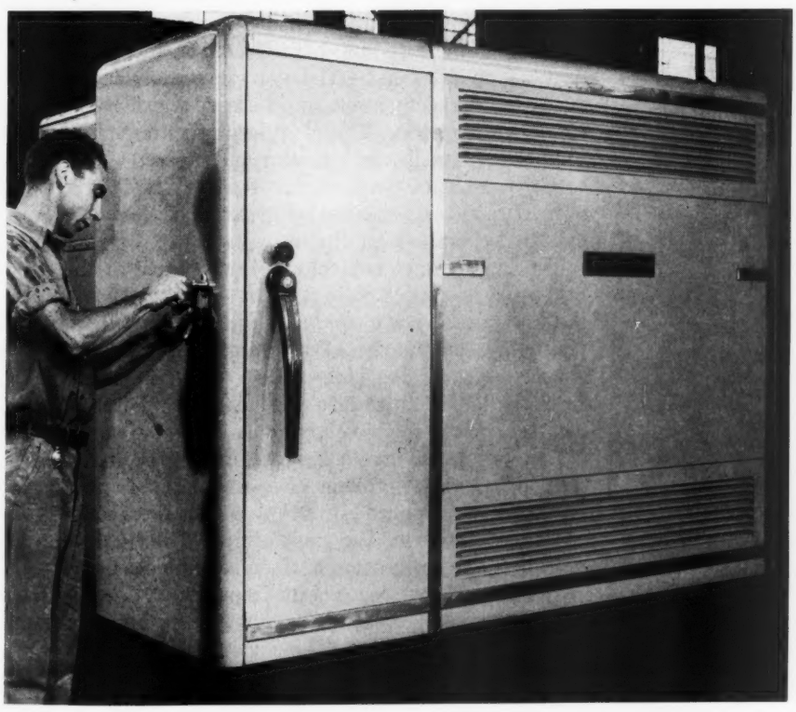
but the building must be ten feet wider than the one in Fig. 2. The floor area required for this modified unit-type substation is, therefore, 5100 square feet. The cost of the electrical equipment for this substation, Fig. 4, is $209 000 or $13.06 per kva of firm demand at the station. Thus, to obtain the greater convenience for maintenance provided in this station, as compared to the station of Fig. 1, the station electrical equipment cost has been increased $30 000. The equipment cost of the substation of Fig. 4 is about the same as that of the substation of Fig. 3. The building and installation cost, however, will be considerably less than for the conventional substation of equal capacity.

The outstanding advantages of the substations of Figs. 1 and 4, and particularly of the substation of Fig. 1, are simplicity, flexibility, decreased 4-kv short-circuit current, safety, and low cost. Combining the transforming and regulating equipment into one unit in the form of automatic tap-changing-under-load transformers, using few buses, breakers, and switches, locating protective and control devices integral with their associated equipment units, and using short metal-clad bus connections between units, all lead to simplicity. The feeder-unit design permits a station to be started economically with only a few feeders and transformers. As the load in the area grows, additional feeders can be added easily by installing additional feeder units. Feeder units can be moved from one station to another. This flexibility permits keeping the substation investment close to the changing-load requirements. It is obtained without any change in the interrupting duty on the 4-kv feeder breakers. The fact that no 4-kv main bus is used and the transformers are not operated in parallel limits the maximum 4-kv short-circuit current and the accompanying system voltage disturbance to a small magnitude. The use of air equipment throughout practically eliminates the hazards of fire and explosion. All of these advantages can be obtained with less substation investment than when using comparable stations of the usual designs.

The substations of Figs. 1 and 4 are particularly applicable for serving areas of relatively high load density, as for example those of 3000 or 4000 kva per square mile, on systems using parallel or network types of subtransmission below 15 kv in underground cable. These stations can be used to advantage either when building new stations or rebuilding old stations on such systems. While the substations described here are applicable to high load-density area, the same basic principles and type of equipment can be used in small unit stations in areas of light load density.

This discussion has been limited to indoor distribution substations. The basic designs of the stations of Figs. 1 and 4, however, can be used for outdoor substations by substituting similar outdoor equipment for the indoor equipment. At present this means using oil-insulated transformers in place of dry-type transformers. When employing these two types of substations outdoors, the equipment costs are about the same as those given for the indoor stations. The outdoor metal-clad switchgear costs somewhat more but this increase is about offset by the lower cost of the oil-insulated transformers. The land area required for the outdoor substations is about a quarter more than for the corresponding indoor stations chiefly because of the greater space taken by the oil-insulated transformers.

Air-Cooled Power Centers



Completely enclosed, this air-cooled indoor power center is rated at 300 kva, three phase, and steps down 2400 volts to 120/208 volts (wye) for factory lighting and power service.

COMMON practice of years standing has relegated the transformer supplying power for a shop or small manufacturing plant to a substation located outside the plant. This substation, whose appearance was considered of no importance, provided service often poor in voltage regulation and high in losses. In modern industrial plants, high-intensity lighting, precision machinery and other factors demand good voltage regulation and low losses in the distribution system.

To supply such power, the transformer, now air cooled, has been brought indoors close to the load and has been combined with the necessary disconnecting switches and control devices. The result is a small, compact, and self-contained substation. Because it is indoors and is associated with modern, sleek equipment, the new power center has been removed from the ugly duckling class and it now harmonizes with the other plant components.

The seven-year record of this type of equipment has established for it a permanent place in plant power distribution. Its low weight and reliance on air cooling permit the installation of the substation near the load center, anywhere in the establishment—on the floor, on an elevated platform, or in the roof trusses.

Air-Cooled Transformer

J. K. HODNETTE
Manager, Transformer Engineering, Westinghouse Elec. & Mfg. Co.

The air-cooled transformer made its debut about seven years ago as an independent development aimed at simplification of indoor step-down installations. Having met with considerable success, it now takes the next logical step. It is coordinated in features and appearance with metal-enclosed switchgear to form unit-type indoor substations.

THE AIR-COOLED transformer is the heart of the indoor substation. It is the design, construction, and operational features of this air-cooled transformer that made possible this new and economical type of unit substation. The use of air-cooled transformers makes possible the installation of complete distribution substations indoors. Many advantages accrue from the use of unitized De-ion air circuit breakers and unitized air-cooled transformers into standardized distribution substations. Among these advantages are smaller space requirements for a given capacity, lower capital investment, greater reliability, and lower maintenance cost. Also, electrical industry has long felt the need for air circuit breakers and air-cooled transformers to remove the fire and explosion hazards incident to the use of liquid-filled apparatus.

The trend towards the development and use of air-insulated apparatus has been well defined for many years. In 1936, a new type of air-cooled transformer was developed in keeping with this movement. This transformer was different from the usual air-blast transformer in that its insulation was principally air, porcelain, glass, and other materials containing the minimum of combustible materials. Such transformers are cooled by natural or forced-draft ventilation.

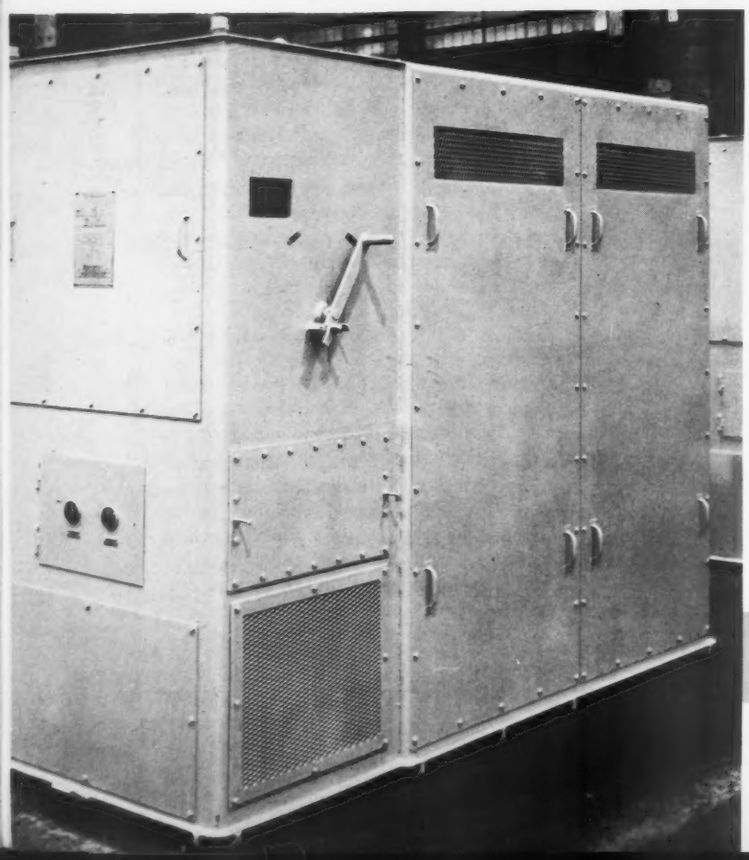
High-Temperature Insulation Used Throughout

The core and coil assembly of the modern air-cooled transformer is of the conventional core form of construction as shown on page 183. The high- and low-voltage windings are symmetrically arranged about the core with the low-voltage cylindrical winding on the inside. Both the high- and low-voltage coils are wound and assembled separately on insulating barriers. They are individually treated with a high-temperature Thermoset varnish to add strength and to bond the conductor and coil insulation into place. The assembled core and coils are likewise treated with high-temperature, heat-reactive varnish. This treatment gives the assembly a smooth, tough, glossy finish, which makes them highly resistant to moisture and dirt.

The insulating materials used in the transformer and the method of assembly have been prime factors in the outstanding successful operation of the air-cooled transformer. The insulation is selected to withstand, without damage, the highest hot-spot temperatures encountered in service. The deleterious effects of dirt and moisture are minimized by taking advantage of free air for the major insulation.

The hottest spots are those between the high-voltage or low-voltage conductors near the top of the coil column. The winding conductors are insulated with glass. Glass is an inorganic substance and unaffected by transformer temperature. It is also practically non-hydroscopic. In applying it to the conductor, a high-temperature bond is used to give the glass mechanical strength. While the bond is heat resistant, the glass is more so and, once located in the coil, is not dependent on the bond. The voltage stresses in the hottest zone are limited to turn-to-turn stress, which is of the order of 100 volts or less. The glass insulation on conductor provides adequate insulation for such stresses. Between coil sections are mica washers that retain fully their insulating properties at temperatures far in excess of those encountered in actual operating conditions.

The high-voltage coil column is supported at the top and bottom by large porcelain spacers. These spacers are shown in the exposed view of the transformer. They are glazed and resist the accumulation of moisture, dirt, or dust. Porcelain spacers separate the high-voltage coils and space the coils from the high-voltage insulating barriers. Porcelain spacers also separate the low-voltage coils from the core assembly. These spacers are unaffected by the temperature of the coils. The high- and low-voltage coils are centered and supported so that an unimpeded air duct separates them and forms the major insulation of the transformer. Dirt falling into this duct drops to the bottom of the case and does not impair the major insulation strength of the transformer. The transformer leads, taps, terminals, and other live parts are supported on porcelain insulators. This construction eliminates creepage surfaces between windings upon which dirt might collect.



Entirely metal enclosed, the air-cooled transformer and related controls are ready for installation as a complete unit in the indoor substation.

r Indoor Distribution Substations

Reliability of Air-Cooled Transformers Established

Trouble-free operation of the major substation apparatus contributes appreciably to the reduction in overall cost of distributing electric energy. In working out the details of design and construction of the air-cooled transformer, particular stress has been placed on details that contribute to the overall reliability of the apparatus such as thermally and electrically balanced insulation design, elimination of horizontal creepage surfaces on which dirt and moisture can accumulate and which are subject to major electrical stresses.

Tests in the laboratory and in the field have been made to prove the sufficiency of the design. Laboratory tests on full-size transformers have been conducted under extreme conditions of moisture and high humidity, with and without load cycling. Such tests have been continued for extended periods of time without noticeable deterioration of the insulation.

The proof of operating reliability lies in service experience. Approximately 2000 air-cooled power transformers are in service, some of them for more than seven years. They are located in power stations, office and factory buildings, mines, chemical plants, and other indoor locations. They are installed without vaults or fire walls. Although many are operating under most severe conditions, none has failed as a result of moisture, high humidity, fumes, accumulation of dust or dirt, or excessive winding temperature.

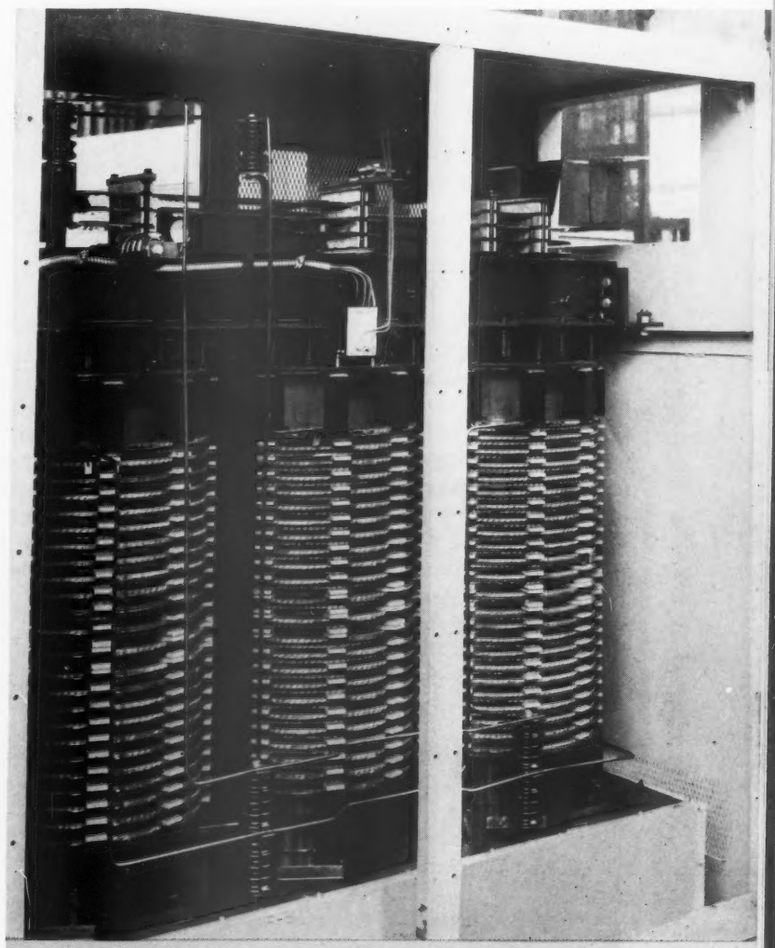
Air Cooling Involves No Loss of Load Capacity

The load-carrying ability of these air-cooled transformers is as good or better than that of liquid-filled transformers. The insulation is not so critical to temperature as the class A insulation used in liquid-filled units, which deteriorates rapidly at temperatures above 120 degrees C. The liquid-filled transformer depends largely upon the heat-storage capacity of the oil, core, and insulation for its overload capacity. The air-cooled transformer, using class-B insulation, is designed to have an average temperature rise of the copper of 80 degrees C and a hottest spot temperature of approximately 160 degrees C, at a 40 degrees C ambient. The glass, asbestos, mica, and porcelain insulations, which are subjected to high temperatures in the air-cooled transformer, can withstand widely varying temperatures without serious deterioration. A number of air-cooled transformers have operated at 150- to 200-percent of rated load for 24 hours or more without interruption of service and with little or no deterioration of the insulation.

Air-cooled transformers are designed so that forced-air ventilation can be applied. By blowing air across the coils and through the coil ducts, the capacity of the transformer can be increased by one fourth to one third. A thermally operated relay is available for automatically operating the fan when the normal operating temperature is exceeded. This relay (the TRA, described on p. 187 of this issue) is placed in the cooling air stream where it leaves the coil ducts and is supplied with a current through the thermal element proportional to the transformer current. The relay accurately follows the winding temperature and, in addition to controlling the fans, gives an alarm if the maximum safe winding temperature is exceeded. Extra transformer capacity for emergency or recurring overloads is provided by forced-air cooling. Protection against damage from excess temperature is provided by the thermal relay, thus increasing the overall reliability of the transformer under abnormal operating conditions with assured safety.

Installation Costs Are Lower

Air-cooled power transformers are lighter in weight and occupy less space than liquid-filled transformers of equal rating. The core and coils are enclosed in light-weight but strong sheet-steel cases with grilled openings at the bottom and the top to provide an inlet and outlet for circulating the cooling air through the transformer. The cases are arranged to facilitate the addition of isolating, or load-break disconnect switches, and connection of switchgear through throat ducts, or by abutting the switchgear cases. The transformer, with the attendant switches and circuit breakers, can be mounted indoors in substation buildings or factories without vaults, heavy foundations, or catch basins required with liquid-filled apparatus, thus minimizing installation costs.



Air and porcelain are the principal insulating mediums used in the air-cooled transformer. High-temperature insulation is used on the coils. The construction allows free flow of air around, between and through the windings. The new protective relay that operates on the basis of copper temperature is mounted on the top of the middle coil assembly in the rising warm-air stream.

Air Cooling Minimizes Maintenance

By combining the high- and low-voltage circuit breakers and the transformer into one unitized structure, the necessity for bushings and outside connections between units is eliminated and the safety of operation is increased.

Air-cooled transformers have inherent advantages from the standpoint of maintenance because of the elimination of valves, fittings, and gaskets. Because there is nothing to leak, such maintenance items are eliminated. In very dirty locations, excessive dirt may accumulate and must be removed. This is accomplished by removing the side from the case and blowing out the dirt with compressed air. Maintenance has reached an all-time minimum with air-cooled transformers for indoor substations.

Combining Air-Cooled Transformers into Substations

Modern distribution substations for central-station systems require good voltage regulation. Voltage regulation can be most economically supplied by means of a three-phase load tap changer. The tap-changing mechanism, including air circuit breakers for current transfer and the control equipment for automatic or manual control, are incorporated into the air-cooled transformer unit.

The air-cooled transformer arranged for connecting to unitized De-ion circuit breakers on either or both high- and low-voltage sides provides almost limitless flexibility in planning and installing indoor substations. Forced ventilation and standardized transformer construction permit the greatest possible flexibility in providing for load growth as well as emergency condition of loading.

Modern air-cooled transformers for indoor service are built to withstand the exigencies of load, temperature, etc. The insulation is stable and can be protected over a long period from excessive temperature or transient voltage.

Indoor Substation Switchgear

The unit-type air-insulated substation is a natural for metal-clad switchgear. With a much longer period of development and service behind it than is possessed by the air-cooled transformer, almost no changes were needed to adapt metal-clad switchgear for use in indoor substations.

P. R. PIERSON
Switchgear Engineer
Westinghouse Electric & Mfg. Co.

THE VALUE of a switchgear using air circuit breakers has been recognized for more than fifteen years. This type of switchgear reduces maintenance and fire hazard. Applications were made originally only where the duty cycle was more severe. This background of years of successful operation under severe conditions has resulted in such a demand for air circuit breakers for general use that they are tending to supersede the oil-type breakers. Applications of these air breakers have been almost entirely of the factory-assembled, metal-clad type. The reliability and economy of this type of switchgear is recognized for industrial and central-station applications, including the heaviest duty power circuits. Metal-clad assemblies of air breakers have a definite place in any program of cost reduction and improvement of service.

Factory-assembled, metal-clad switchgear is available with air circuit breakers for either outdoor or indoor service. When the installation is indoors, the building housing the switchgear can be of the simplest construction, as the switching equipment is self-contained and requires no complicated cell structure, supporting framework, or interconnecting control conduit runs. Aside from the foundation and primary conduits, the building provides only weather protection and facilities for attendance and maintenance. The outdoor factory-assembled units require only a suitable supporting foundation. The switchgear itself is enclosed in a completely weather-proofed case.

To reduce costs, metal-clad switchgear is now built from highly developed standard designs for which engineering and factory procedures are established. These designs meet or exceed accepted standards of construction—material, insulation levels, and duty requirements—specified by NEMA and AIEE for as-

Flexitest relays and meters have been used extensively in this 15-kv metal-clad air-circuit breaker assembly. This permits installing the switchgear while the relay and meter elements are being tested and calibrated in the laboratory.

Outdoor metal-clad switchgear with removable air circuit breakers similar to indoor equipment, rated up to 15 kv with interrupting capacities from 50 000 to 500 000 kva. Weatherproof housings provide ample room for inspection and maintenance.

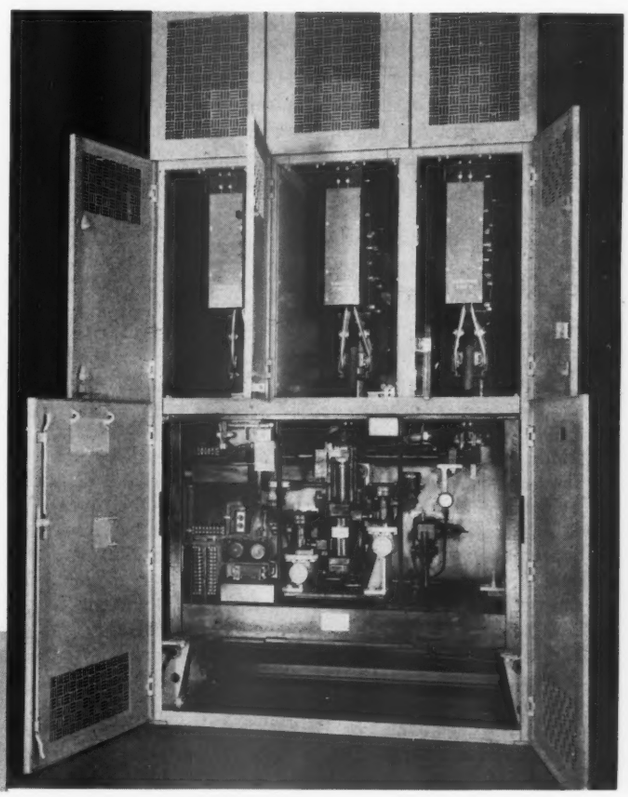
sembled switchgear. They can be manufactured economically and with assurance of satisfactory installation and operating results. On the other hand, special features involve expensive and time-consuming engineering, and special tools and fixtures. Also, special designs involve extra labor, instructions, and supervision. The effect on cost of special features involving design change is obvious.

Because standard factory-assembled switchgear is designed to meet the average requirements of all users, it may not include all the features desired for the local operation and maintenance peculiar to an individual operating company. In order to take advantage of the economies of standardized switchgear, it may become necessary to adapt operating procedures to the modern equipment. In most cases, variations in operating and maintenance procedures can be provided for by special adapter devices, which can be used in conjunction with the standard base units. For example, grounding either the supply or load terminals is provided by a simple device which can be inserted in place of the circuit breaker. This makes the terminals available for connecting to ground. Another device, consisting of a remotely operated, spring-closed disconnecting switch, can be inserted in place of the breaker for grounding either set of terminals. Provision for cable phasing out and testing can be incorporated in these devices.

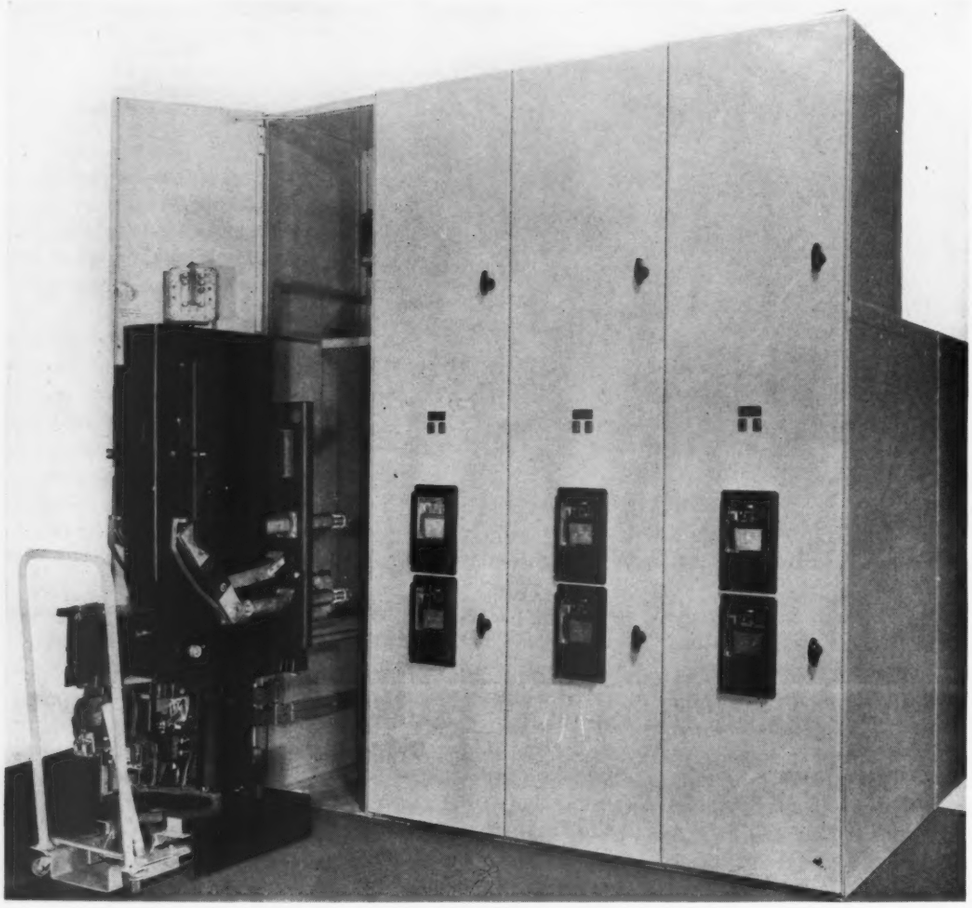
Flexibility of installation and provision for extra devices is obtained by the use of the standard switchgear units combined with standard auxiliary compartments, bus runs and enclosures. The use of these compartments, which can be equipped with extra devices and will accommodate unusual arrangements, keeps the structure uniform and retains all the accessibility and safety features of standard metal-clad switchgears. For example, where emergency buses are required, the use of two base-housing units, complete with buses, provides safer operation and permits better maintenance than a breaker unit and transfer bus combined in a single special unit. If a transfer bus is preferred, a separate transfer bus structure is recommended so that the structure containing the bare disconnecting-switches is not integral with the fully insulated unit.

The use of assembled switchgear on circuits requiring revenue metering in some cases involves certain special handling of current transformers and meters to accommodate the tests required on these devices. The tests of instrument transformers can generally be performed by the manufacturers and certified test data supplied with the equipment. The use of modern "Flexitest" meters makes it possible to ship the meter elements to the user for tests while the factory assembly is being completed. The tested meter can then be inserted into its mounting during installation of the switchgear at the service location.

The switchgear proposed for the basic substation shown in Fig. 2 on page 179 consists of standard, horizontal draw-out, metal-clad, air circuit-breaker units, rated 500 000 kva and having 15-kv class insulation for the primary incoming lines and bus-sectionalizing circuits. The necessary protective relays of the "Flexitest" type are located on the front panels of the breaker units together with the necessary meters and control devices. Bus-enclosure compartments are located between the breaker units and provide for the tap-offs to the



Station-type switchgear is supplied with compressed air circuit breakers for primary-circuit control where higher insulation values are desirable. These units interrupt 500 000 to 2 500 000 kva at service voltages in the 15-kv, 22-kv, and 34.5-kv classes. This class equipment provides metal phase segregation and high insulation levels.



Light-duty, horizontal draw-out metal-clad switchgear of this type is equipped with air circuit breakers. These breakers are available in standard unitized assemblies for service voltages up to 15 000 volts with rated interrupting capacities from 50 000 to 500 000 kva.

power transformers and space for necessary potential transformers. The tap-offs consist of short metal-enclosed bus runs spanning the maintenance aisle. Standard light-duty, horizontal draw-out, metal-clad air circuit breakers rated 50 000 kva and having 5-kva class insulation control the secondary circuits. A bus transition compartment between the breaker circuit and the transformer provides space for the adapter connections between the switchgear bus location and the transformer terminals and for the necessary potential transformers. Control, metering and protective relays are mounted on the front panel. This design uses a simple circuit arrangement and is economical of building space.

This station takes advantage of the low cost and reliability of standard metal-clad switchgear. The present downward trend of switchgear prices can be furthered only with highly active standard units. On the other hand, there is a definite upward trend in prices of metal-clad switchgear where special basic units are required.

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An Automatic Watchman for Air-Cooled Transformers

A device for protecting air-cooled transformers must take into account not only the load being carried at any instant but also the recent load history. It should integrate the heating effect of immediate and recent loads. A new thermal bimetal relay does this, permitting the completely air-cooled transformer to be overloaded with safety to its thermal limit.

E. W. TIPTON
Transformer Engineer
Westinghouse Elec. & Mfg. Co.

THE inherent overload capacity of air-cooled transformers can be utilized to the fullest with complete safety by a new protective system. This brings to the air-cooled transformer the same degree of safe utilization that has been possible for several years with oil-filled transformers under the scheme known as operation by copper temperature. In this scheme the index of safe loading is provided by a device that follows the temperature of the copper where the heat originates—instead of being guided by some more approximate criterion that does not consider both the present and previous loads as well as the temperature of the cooling medium.

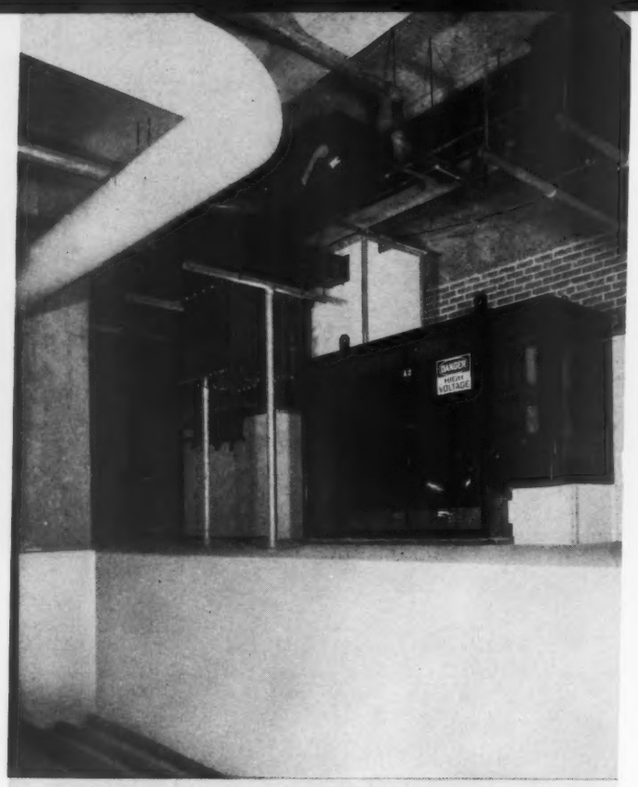
The large volume of liquid in oil-filled transformers serves to give them a higher capacity for heat storage than similarly rated air-cooled designs. This is partially compensated, however, by the larger core and coil structure required in the air-cooled transformer to provide the necessarily larger insulation clearances. A greater compensation results from the higher temperature rise permitted by the insulating material used in the air-cooled transformer. Most of its insulation is made from porcelain, glass, and mica, which are class-C materials. In the high-voltage winding, only porcelain spacers and glass-tape insulation plus a high-temperature plastic for moistureproofing are in contact with the coils. In the low-voltage winding, asbestos-block spacers are used. The block spacers and the plastic treatment are nominally class-B materials. However, safe temperature limits of both are higher than the 130 degrees C maximum limit set by the AIEE standards for class-B materials. The new thermal relay is calibrated to utilize the capacity made available by working these materials at high temperatures.

Mounted above the coils, the TRA relay is in the stream of heated air emerging from the transformer—its operation based on copper temperature.

The AIEE and ASA standards do not, at present, recognize any materials—other than those in class C, which are more or less unlimited—as having a safe temperature limit higher than the 130 degrees C permitted for class-B materials. However, some synthetic varnishes now in use are cured at temperatures higher than 130 degrees C. Some varnishes withstand temperatures of 180 degrees C. Bonded-mica plates can be used to temperatures of 500 degrees C. Porcelain and glass fabrics are practically unaffected by such elevated temperatures.

Many air-cooled transformers built with these materials have been in continuous service for periods up to seven years. Operated continuously at full load with an ambient temperature of 40 degrees C, these transformers may have hottest spot temperatures of 160 degrees C. Although these trans-

Particularly suitable for underground use are air-cooled transformers. Equipped with TRA relays, they deliver maximum energy with safety.



Air-cooled transformers are not exacting as to mounting requirements. Being relatively light and requiring no tanks of coolants, they can be installed close to associated equipment and up out of the way as here shown, saving valuable space.

formers have been frequently overloaded—in one case as much as 150-percent load for 30 hours—none has given any trouble resulting from overheating.

Relay Composition and Operation

The scheme of thermal protection of air-cooled transformers requires three pieces of equipment: a thermal relay (type TRA), a control panel, and a current transformer. The relay proper consists of two bimetals connected in series with the secondary of the current transformer, as shown in Fig. 1. One bimetal provides a warning of impending overtemperature, the second, operating at a higher temperature, takes remedial action. Each bimetal is arranged so that when it is heated it deflects and closes a low-energy switch. These switches can be moved by calibrating screws so that the contacts are closed at any desired temperature.

Each of the two bimetals is responsive to two factors. One is the temperature of the cooling air, the other is the current flowing through the transformer. The relay is located in the transformer with the bimetals in the hottest air from the coil-cooling ducts. It is placed directly above the coils and is shielded on the sides by a "chimney" which directs hot air from the coils past the bimetals. Thus the bimetal is heated by the warm air discharged from the transformer coils. This construction protects the thermal elements from undesired drafts and radiation and assures that the thermostats assume a temperature proportional to the hot-air temperature. In the concentric-coil core-form construction normally used in Westinghouse air-cooled transformers, the highest temperature cooling air comes from the inner coil because this air can enter only at the bottom of the coil and is progressively heated until it leaves at the top of the coil. Also, in this type of construction, the highest temperature occurs at the center of the coils and between the two windings. The temperature falls off toward the core and toward the outside of the outer winding. The relay is, accordingly, placed above the duct at the outside diameter of the inner winding. In this location, the relay bimetals assume a temperature proportional to the highest cooling-air temperature.

The bimetals are further heated by current that flows through them from a current transformer. This current is proportional to the load current. The resistance and cooling surface of the bimetals are so chosen that the temperature gradient to the cooling air is proportional to the gradient from the transformer-winding hottest spot to the cooling air. This design assures that the bimetal temperature follows the hot-spot temperature-time characteristics of the winding.

The relay control panel is arranged for connection to conduit for taking out control circuits and for bringing in the control energy supply. One of the bimetals is so calibrated that it closes its contact when the transformer is approaching its maximum safe operating temperature. When the relay contact closes, an auxiliary relay on the control panel operates to light a signal light on the panel. A second contact on the auxiliary relay is wired to a terminal block from which it can be connected to other signals mounted elsewhere.

The auxiliary relay in the signal circuit is self-sealing. After the signal lamp is lighted by an overload of sufficient duration, the relay must be manually reset by means of a switch located on the control panel. Self-sealing makes certain that a record of the overload is maintained even should the load return to normal in the absence of an operator.

The second bimetal closes its contact to a second auxiliary relay when the transformer reaches its maximum safe tem-

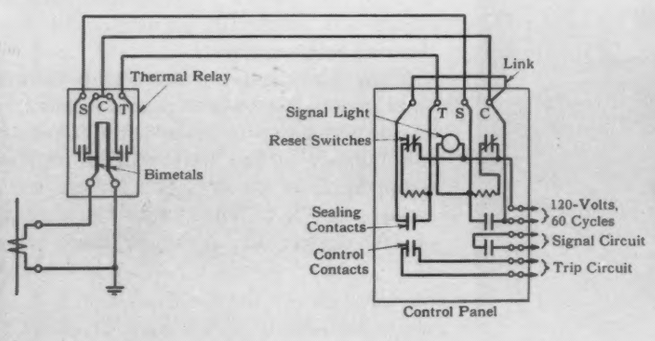
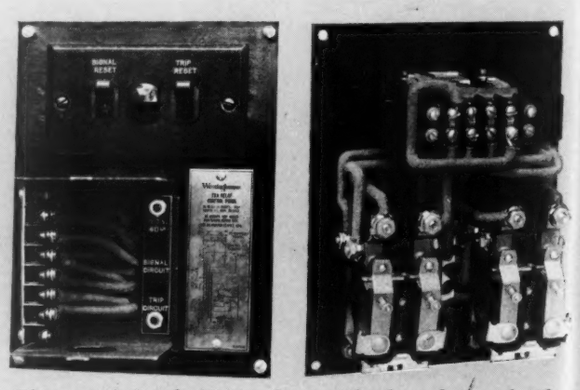
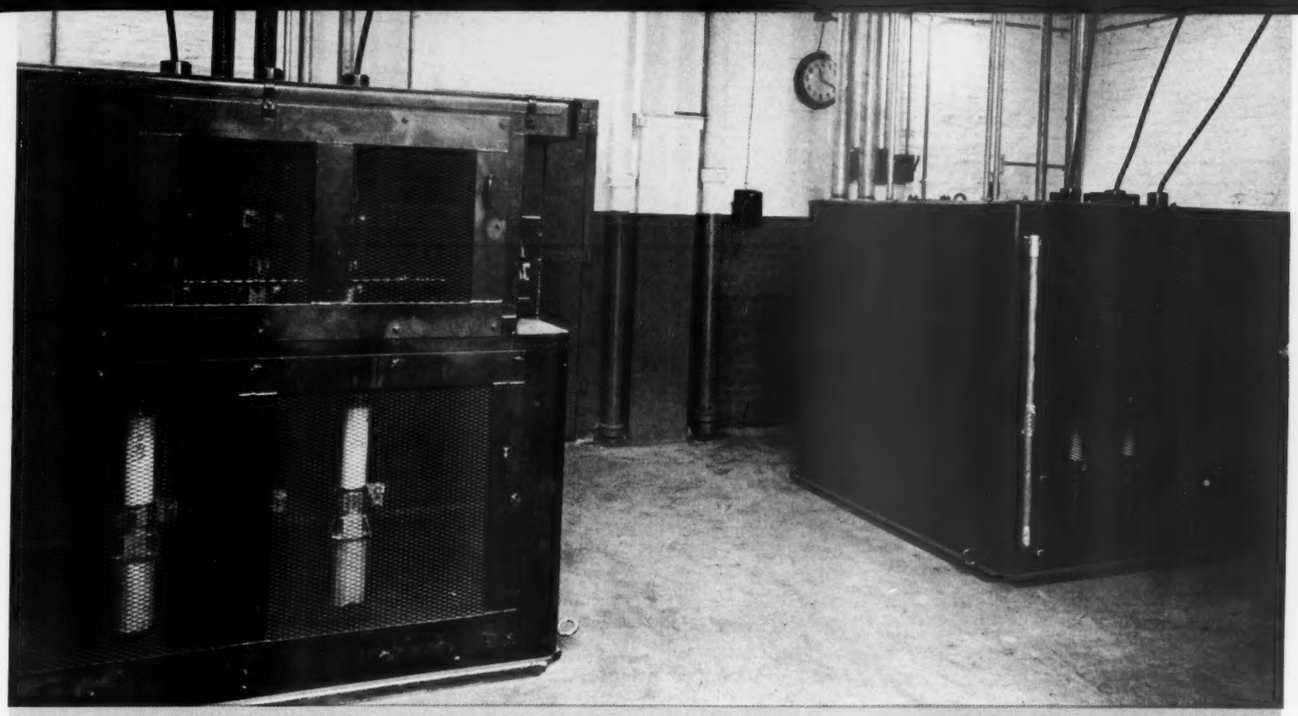


Fig. 1—*Wiring diagram of the TRA relay and control panel.*



The controls for the TRA relay are simple and rugged. The panel can be installed remotely at any convenient location.



Air-cooled transformers for indoor installation require none of the extensive fire precautions necessary for liquid-cooled equipment. Capable of heavy overloads, these transformers now carry them with assurance, guarded by relays that operate on the basis of copper temperature.

perature limit. A circuit from this auxiliary relay is carried to a terminal block, and is designed for connection into the trip circuit of the main circuit breaker. Used in this way, the relay disconnects the transformer from the load before windings are damaged. This auxiliary relay in the breaker trip circuit is also arranged to be self-sealing and is provided with a reset switch. It can be operated non-sealing by removing a link from the back of the panel. With the latter arrangement, the control circuit can be connected so that the circuit breaker can be reclosed as soon as the transformer and relay cool sufficiently to permit the bimetal contacts to open.

Both of the auxiliary relays on the control panel are designed so that their contacts can be reversed to give normally closed operation of the signal and control circuits. These relays serve to keep control circuits independent of the temperature relay circuits. The contacts on the auxiliary relays are accessible. They can carry control-circuit currents up to 12 amperes continuously and interrupt currents of 30 amperes at 120 volts, 60 cycles. Auxiliary relays are available for standard control-circuit voltages.

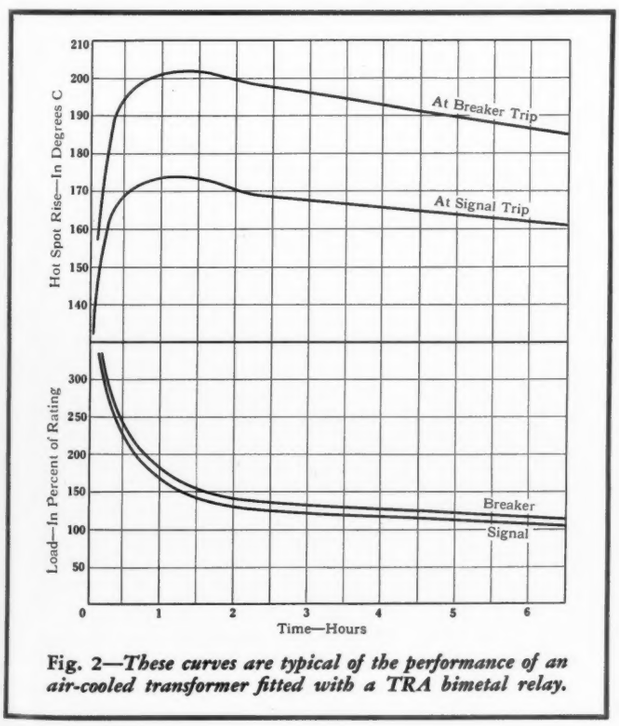


Fig. 2—*These curves are typical of the performance of an air-cooled transformer fitted with a TRA bimetal relay.*

A typical overload performance curve for a transformer equipped with a TRA thermal relay is given in Fig. 2. The relay integrates the effects of any series of short-time overloads of various magnitudes and durations and interprets the result in terms of hottest spot winding temperature. Useful overloads can be carried up to the limiting safe winding temperature. Excessive overloads or short circuits produce sufficient heating in the relay bimetal, from current alone, to close the contact immediately. This action is fast enough to protect the transformer against short circuits. Current transformers supplying the relay do not saturate until sufficient current is supplied to give this protection.

Relay Provides Protection Plus

For such an essentially simple device the thermal relay for air-cooled transformers has an impressive list of accomplishments. The relay permits safe utilization of the transformer short-time overload capacity. It protects the transformer from damage by short-circuit currents. It gives a signal when the transformer approaches an unsafe temperature; and, if the signal is not heeded, it disconnects the load before the transformer is damaged. On forced-cooled transformers the relay can be used to start the fans when the winding reaches a predetermined temperature. It greatly extends the usefulness of the air-cooled transformer for locations where explosion-proof and fireproof transformers are required.

Heretofore, the air-cooled transformers have had no protection and no indicators showing overload. Now, however, with the new TRA relay, the transformer is fully protected from dangerous overloads, gives indication of overload when it exists and permits an overload of a size and duration that is within the limits of safe operation of the transformer.

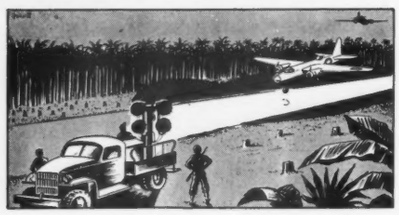
What's New!

A Lamp to Their Feet

TO THE homing Allied fliers, new portable lighting equipments are the lamp in the window and the welcoming porch light to guide them in and provide safe landing. Mounted on trucks, these airfield-runway floodlighting units derive their electric power from the same source that makes them mobile. Westinghouse

airport beacons and airport floodlights provide the light. Davey Power Take-Off units supply the drive connection from the truck motor to the generating equipment for the floodlights.

Of particular use in war areas, where aviators must follow tortuous routes on the return home, are the mobile beacons. These 24-inch beacons, fitted with two 500-watt, 115-volt lamps (one for emergency use), are mounted on an enclosed



truck that houses the beacon when not in use. When in operation, the beacon is raised through a hole in the truck roof. The truck is supplied with a complete 115-volt, portable gas-engine-generator set and tripod mounting for the beacon for use in locations where the truck cannot penetrate, such as wilderness mountain tops. With this portable beacon and power supply are provided complete camping outfits for the personnel.

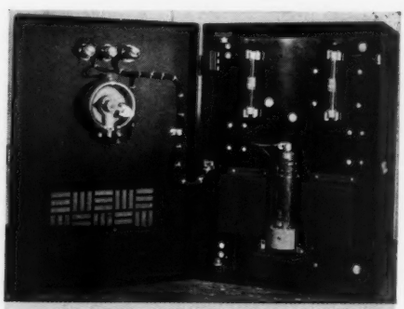
The sudden need all over the world for airports, complete with night-flying facilities, resulted also in trucks mounting floodlighting equipment whose beams can effectively light the proper runway for about a mile. Four floodlights with varying optical characteristics and using 3000-watt, 32-volt lamps, permit complete runway lighting with overlapping light patterns covering the entire area while the truck is stationed from 100 to 500 feet off the runway.

Power is derived from the truck engine which drives a 240-volt, a-c generator. This voltage is transformed to 32 volts. In addition, provision is made so that, when not required for floodlight use, the truck can be used to supply power needed at the airport for radio, local lighting, or power-tool use.

A self-contained unit, this equipment can light a mile-long runway in a remote airfield or supply power for machine tools and lighting circuits.

New One-Half Cycle Weld Timer

FOR MANY production operations involving radio tubes, pig-tail resistors, terminal lugs, relay-contact tips, and similar small objects, hand soldering was the method used to join the parts. Because these parts are mostly metals of high conductivity such as aluminum, copper or silver, the heat of the weld was conducted away from the weld point so fast as to keep the metal below the proper welding temperature. A new synchronous spot-welding timer and heat control overcomes this difficulty by supplying high-current impulses for intervals of one-half cycle or



This weld timer supplies high-current impulses for half-cycle intervals.

less. The sharply peaked current impulses raise the weld point to welding temperature before the material being welded can conduct it away.

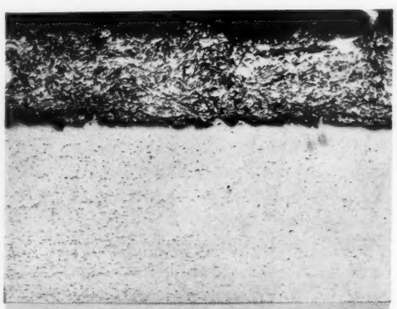
The timer is furnished as a separate control for existing bench and tong welders, or in combination with a small welding transformer. Operating from a 50/60-cycle, 230/460-volt supply line, the timer uses a single thyratron tube that serves the dual purpose of rectifying alternating current to charge a firing capacitor and also to fire the small ignitron power tube. Heat control is achieved by shifting the phase of the thyratron grid with respect to the line so that with each operation, the current is taken from the same portion of the half cycle. The timing and amount of weld heat is, in this manner, precisely controlled.

In actual operation, the thyratron, acting as a single-phase, half-wave rectifier, charges the firing capacitor from the line. The firing capacitor then triggers the thyratron, which causes the latter to fire the ignitron in the welding transformer circuit. The amount of current flowing into the weld depends on the phase-shift control setting. Because only a single loop of welding current is used, the thyratron can be fired at a time leading (or in ad-

vance of) the zero point of the steady-state normal current wave of the welding transformer. This enables greater current to be controlled for this time interval. Obviously if the thyratron were fired in phase with the steady-state current wave the welding current available would be the normal rms current of the transformer. By this advanced firing of the thyratron, a transient current peak of considerably greater magnitude than the normal current wave is produced.

A New Finish for Outdoor Capacitors

PROTECTING the surface of an outdoor-service capacitor is a special problem. If the case of a transformer or other outdoor equipment is damaged, generally the equipment can be salvaged, re-cased and restored to duty. Let a capacitor case rust



This photomicrograph shows the close bond between the sprayed metal and case.

through and the capacitor is a total loss because it cannot be repaired in the field or at the factory. Spraying the cases of Inerteen-filled capacitors with atomized molten zinc has increased the life span of the capacitor manyfold over previous methods of protection.

Capacitor cases have ordinarily been protected by three coats of paint. Such protection is particularly vulnerable to scrapes and blows. Capacitors are generally mounted close together on poles or racks. Once installed, it is nearly impossible to give them an adequate painting without removing them from service. It is necessary that every handler of the capacitor in shipping, storing, installing and servicing be cautious to avoid scratches or abrasions in which corrosion would have a chance to start.

Zinc has long been recognized as an excellent protective coating. It is anodic with respect to steel so that when a breach in the coating is made, corrosion does not set in, but the adjacent coating protects the base metal. It has been used widely as a protective coating, generally in the form of a hot-dipped galvanized finish. However, this process is not adaptable to coating capacitor containers as the heat may be damaging to the working elements.

Metallic zinc is sprayed on the capacitor case as easily as ordinary paint.

Some eight years ago a technique was developed for applying molten zinc with an atomizing spray. This method has proved effective on large, outdoor structures, pole-line hardware, sea-going equipment, etc. The zinc can be applied to any desired thickness and is easily made several times as heavy as hot-dipped galvanizing, thus giving a life proportionately longer.

The capacitor cases are sprayed with three or more separate coatings until the surface is covered to a minimum thickness of 0.006 inch. The zinc coating overlaps the non-ferrous insulator-base mounting flanges giving complete protection at all points.

The life of the sprayed-zinc coating will vary somewhat, depending upon atmospheric conditions. In general, the sprayed finish will protect some six times longer than hot-dipped galvanized finishes.

In addition, the sprayed finish is quite resistant to scratches and abrasions. It requires a severe gouge to injure this protective coating. Ordinary rubs and scratches compress the sprayed-on zinc surface. The matte finish of the sprayed particles is smoothed over. Thus, one of the big causes of the onset of corrosion, surface scratches, is eliminated.

Proportional Lighting

GOOD general lighting is now standard practice in most progressive industrial plants. In many of the more modern establishments, illumination intensities of 50 or 60 footcandles are common. Even with this excellent general lighting, there are many local areas that require much higher levels of lighting for quick, accurate seeing. For example, on machine-tool cutting points, fine bench-assembly and inspection work, 100 to 300 footcandles may be required. This is accomplished with "Proportional Lighting"—good general lighting, plus good supplementary lighting. This additional high-intensity lighting is economically provided by Focalaire units mounted right on the machine or bench. Focalaires are adjustable reflector fixtures using a standard 100-watt incandescent lamp.

Available in many sizes and base mountings suitable for bench and table operations, small machine and large machine-tool use, these fixtures are simply constructed and are supplied with cord and plug for connection to any standard outlet. Three reflector styles are available.

In addition to good general lighting, high illumination intensities are needed for critical seeing tasks. Focalaires provide 100 to 300 footcandles in the work areas.

Illumination levels of 100 to 300 foot-candles can be obtained on the work area by correct adjustment and use of the proper reflector.

These lamps do not replace, but supplement general lighting for the more critical seeing tasks involved in inspecting, precision machine tool operating, gauging and similar work involving discrimination of fine detail.

New Semi-Portable Weld Control Unit

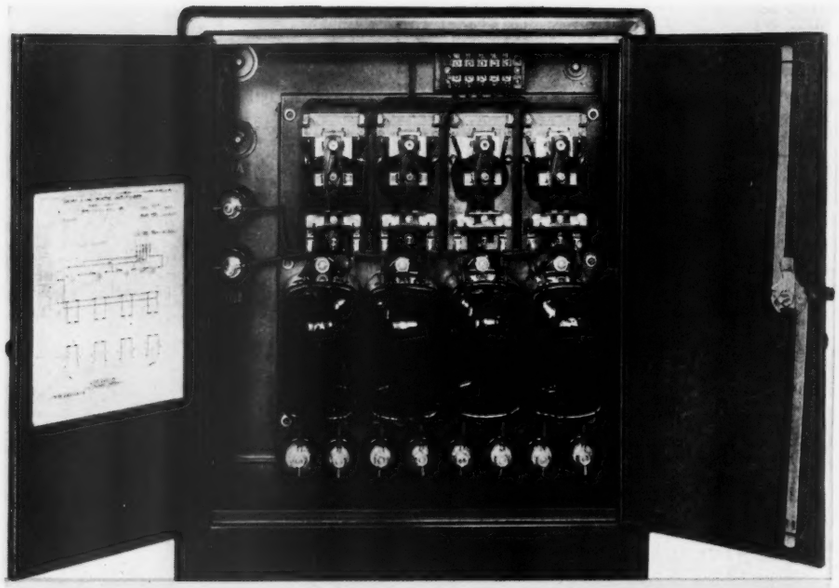
THE demand for fast and accurate repetitive welding has resulted in the development of a number of controls, largely of an electronic nature that insure the quality as well as the speed of resistance-welding operations. Developed individually to meet specific needs, this family of controls has been for the most part mounted individually on the machine itself, on the floor, or on nearby walls. A new type (SP-9C) resistance welding control combines the several necessary units in a semi-portable housing. It is a synchronous weld timer with built-in sequence panel, weld recorder, lock-out device, and voltage compensator. It is completely self-contained and can be moved from location to location and used with any gun or pedestal welding machine.

Timing is synchronous and precise and thus high starting transients are avoided. Welds can be timed for one to 30 cycles in 15 steps.

Heat control is achieved by use of a phase-shift circuit. By this method, only a portion of the line voltage is made effective. Welding current is varied from 100 to 20 percent (heat varies from 100 to four percent.)

Variations in line voltage are compensated to prevent variation in heat at the weld. By means of an electronic circuit, any drop in the line voltage causes the automatic phase-shift circuit to function. This causes the weld current to increase sufficiently to provide the proper weld heat despite the line-voltage drop.

A weld recorder is a built-in feature of this new synchronous weld timer.



Combined in one cabinet are the relays and series plug-type absolute cutouts. This selector cabinet controls the airplane landing contact lights on four different runways.

The sequence panel provides the control of the order and duration of the elements of the welding operation—squeeze, weld, hold, off. The unit can be used for roller spot-welding operation.

An unusual feature of this control unit is the weld recorder as an integral part of the control. On a continuous tape is graphically recorded each weld. Should any bad weld appear on the record, a lock-out device, that is tied in with the recorder, trips the proper relays on the relay panel to halt the welding operation. The operator is given a sound warning and must correct the trouble to make the welder operate again.

A one-half cycle release also trips out the welder if a series of uni-directional half cycles (either positive or negative) is passed by the welding control. This prevents damage to the welding transformer through progressive saturation and the resulting high d-c component.

A New Runway-Selector Cabinet

THE CONTROL-TOWER operator at an airport has all flying information—wind speed and direction, ceiling plane location, etc.—at his fingertips. Also at his fingertips are pushbuttons to light the proper runway for an incoming plane. Behind these pushbuttons is a system of relays and contacts that must operate with decision and reliability to insure the safety of the landing aircraft. This runway-selector mechanism meets Army-Navy-CAA requirements and combines in one cabinet all the parts formerly installed at random on walls or switch racks.

Usually, the contact lights outlining the runway to the pilot for a night landing are connected in series like a string of Christmas-tree lights. Each runway has its own string of lights. All of the contact lights are connected in series to the secondary of the constant-current regulator supplying the system. The relay contacts are closed when the relay is de-energized, short circuiting the strings of lights. When energized by the control-operator's pushbutton, the relay opens, permitting the current to flow through the series of lights required for the particular runway to be used. The runway-selector cabinet provides control elements for four light circuits on four different runways. Any single circuit or all of them, or any combination of the four, can be used at one time.

An important feature of this equipment is the series plug-type absolute cutout. The string of contact lights at the runway is subject to periodic checkup in addition to the necessary maintenance and light replacement. The series cutout protects the personnel by opening both sides of the line between the relay and the string of lights. The cutout plug is a porcelain-backed arrangement that may be physically removed from its receptacle. When the cutout is removed, the spring contacts in the receptacle that are connected across the relay terminals come together. Thus, even if the relay is energized by the remote-control pushbutton at the operator's booth, the series-cutout contacts short out the current and protect personnel working on the circuit.

The relays, series cutouts, and necessary input and load terminals are contained in a metal cabinet, approximately two feet wide, three feet high, and nine inches deep. The power input is from a constant-current source supplied at a primary voltage of 2300 volts. The relay coils are supplied from a 120-volt a-c control circuit.

PERSONALITY PROFILES

The train that carried *Otto Ackermann* on his first trip to Pittsburgh, shortly after coming to this country from Germany, rolled swiftly through the twilight of a mid-April day in 1924. Treeless hills, barren save for occasional homes, starkly silhouetted in the growing dusk against the birth-fires of steel, made him think that the city was above the timber line and to him came visions of excellent skiing. The skiing failed to materialize, but a job with Westinghouse did. Starting as a casting trimmer, he was soon transferred to the drafting room of the Transformer Engineering Department where his education could better be brought into play (Technische Hochschule, Munich, B.S., E.E. 1922). Later he became a design engineer in the Motor Division and was so occupied until 1927. At that time he shouldered the responsibility of designing the first cathode-ray oscillograph for the Company. Ever since, Ackermann has been closely identified with the problems and apparatus associated with field investigation of lightning, protection problems, steep-front surges. In the summertime, when he is not chasing down the "bugs" in a recalcitrant piece of equipment, Ackermann is on the prowl for further additions to his remarkable collection of moths.

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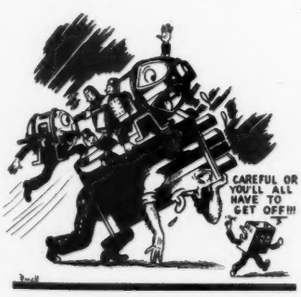
E. W. Tipton early decided what he wanted to do—and where. He finished part of his student course at Westinghouse between his junior and senior years at the University of Kansas where he received his B.S. in Electrical Engineering in 1925. He entered the employ of Westinghouse the same year and finished the remaining portion of the student course in ten months. Tipton further improved the shining hour by completing a course in the Design School, supplemented by courses



at the University of Pittsburgh. In 1925 he was moved to the transformer plant at Sharon where he has been occupied with development work in small power transformers, network problems and, of course, air-cooled transformers. His hobby is botany, nicely blended with color photography. Tipton has for years specialized in wild flowers and has over 700 specimens ranging from delicate, retiring plants that yield their beauty only to the most assiduous seeker, to the most blatant and deplorable types of weeds. His collection is embellished with over 400 color slides of the prettiest and rarest.

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And in this space we have *E. Beck*, winner to date in the Personality-Profile Derby. For information regarding him on his fourth appearance in these pages, we refer you to the issues of February, '42, November '42, and March '44.

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In *John S. Parsons* we again extend a welcome to a prior contributor. In fact, one of his previous efforts was printed in the first issue of the *ENGINEER*. Receiving his technical education at the U. S. Naval Academy and Georgia Tech (B.S. in M. E., '21), he came to Westinghouse in 1921. Entering the Relay Engineering Division, he was identified with that group until 1930, when he moved to the Central Station Division where he specializes in power-distribution problems. On this subject he speaks with the authority of experience and ability, as 40 fundamental patents well attest.

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P. R. Pierson's rich fund of knowledge about metal-enclosed switchgear comes from many years of working with it, from every angle. He first encountered it—or should we say it first encountered Pierson—very soon after the switchgear units first donned steel jackets. He was then in electrical service work for Westinghouse in Chicago, so he first learned about metal-clad switchgear from its behavior in service. In 1926 he came to East Pittsburgh to assist in the design of this switchgear, still just trying to win its place in the industry. In 1936 he became Section Engineer in charge of metal-enclosed switchgear design. He has, then, been associated with this development from the beginning and has had a personal hand in many of its developments, particularly in the high-current class. Pierson obtained his technical training at Clarkson College, graduating with a B.S. in E.E. in 1916.

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A mechanical engineer gone electrical is *J. K. Hodnette*. How well he has changed his spots is attested by the inclusion of his name in 1940 among the nationwide roll of outstanding living inventors. For his many transformer improvements he received the Westinghouse Award for Merit. Graduating from Alabama Polytechnic Institute in 1922, he came with Westinghouse the following year and furthered his schooling in the evening at Carnegie Institute of Technology. Early recognizing the possibilities in Hipersil core steel, as manager of Distribution Transformer Engineering, he led in the redesign work necessary to take advantage of the characteristics of the new material. Hodnette is now Engineering Manager of the Transformer Division at Sharon, Pa.

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Few have risen as fast in the engineering world as *Jose Bejarano*, native of Mexico. He was born in Mexico, D. F., and spent his early boyhood there, but came to the States for his college training, at Columbia University. Not content with one degree, he obtained three: B.A., 1936; B.S. in E. E., 1937; and M.S. in 1938. In between his bachelor of science and master degrees he sandwiched a period at Westinghouse on the student-training course. In 1938 he went to work in the Westinghouse Central Station Department, and transferred the next year to the Westinghouse Electric International Company. A year later he became Assistant Manager, Central Station and Transmission Department, which was fol-

lowed in 1943 with managership of the Special Projects Department. Although he has been with the International Company a short time, he has had a hand with the Chilean hydroelectric program, the electrification of the Chilean State Railways, and many power projects in Mexico.

POWER ON THE MOVE

The vertical tubes in this condenser car, one of two used in the power train, are covered with myriads of copper cooling vanes. Air is drawn through these vanes and exhausted from the funnel-shaped stacks on top of the cars at the rate of 800 000 cubic feet per minute. (See p. 176.)